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Investigating the Effects of Display Design on Unmanned Underwater Vehicle Pilot Performance

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ABSTRACT

The aim of this research was to investigate the effect of different user interface designs on the performance of an Unmanned Underwater Vehicle (UUV) pilot. Participants in this study were 23 males and 3 females who took part in a remote piloting experiment. Participants were each presented with three display designs; a display analogous to the current Mine Disposal Vehicle (MDV) Baseline display, an Inside-Out (fixed vehicle) design and an Outside-In (moving vehicle) design and were asked to fly a simulated mission. During each condition, Situation Awareness (SA) and Human Performance (HP) measurements were taken. Results indicated a significant relationship between display design and level of situation awareness and human performance on a number of measures. Significant differences in situation awareness were observed between display designs for vehicle roll and depth. Results also indicated significant differences between the display designs for the number of control reversal errors observed for roll, the number of waypoints reached, the final odometer reading and the speed of approach to the first waypoint. A significant preference was revealed for the Outside-In display design. Results from this study indicate that UUV pilot situation awareness and performance can be enhanced by modifying and improving display design. Results of this study have implications for the use of unmanned vehicles in the wider air and land domains, as well as the underwater domain.

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Executive Summary

Over recent years, Unmanned Vehicles (UVs) have emerged as a sensible and practical alternative to human involvement in many situations. As such, these vehicles have been embraced by commercial and military establishments around the world. Increasingly, UVs of all forms are taking on roles, particularly in the military environment, where the risk to human life is considered too high or where environmental conditions are too inhospitable for humans.

As part of the UV family, Unmanned Underwater Vehicles (UUVs) constitute an area of growing interest due to their ability to operate at depths and in areas that are inaccessible to humans or other types of vessels. These vehicles are used extensively for underwater search and salvage, inspection, surveying, scientific exploration, and mine countermeasures. Owing to their operational capabilities, the Royal Australian Navy (RAN) employs UUVs to complete a wide range of tasks, including mine counter-measure applications and hydrographic surveillance operations. Due to the important roles these vehicles assume in such situations, it is necessary to ensure superior systems and technologies are in place in order to facilitate optimal performance - by both human and machine.

Unique in terms of their operation, UUVs are operated from a location external to the pilot's present position. The ultimate goal of any unmanned system is to provide a pilot with the capability, via the use of sensors, to act and perform as if he or she was really present at the remote location. In support of this, it is necessary to have correct and relevant information to aid completion of an operational task.

The Human Computer Interface (HCI) used in the operation of a UUV is of particular importance as it has the potential to influence pilot performance and degrade mission effectiveness. Due to the complexity of operating this type of vehicle, special consideration needs to be made when assessing pilot information requirements, and the subsequent design and presentation of information displays. Information such as; pitch, roll, heading, depth, speed and vehicle location can be considered critical to the task at hand and as such, pilot operator displays must present this information in a manner which is accurate, accessible and easily interpretable.

The integration and presentation of vital information helps provide an overall understanding to the pilot of their position within the context of their operational environment. This understanding can be described in terms of a pilot's level of Situation Awareness (SA). As a concept, SA describes "the perception of elements in the environment within a volume of time and space, comprehension of their meaning and projection of their status into the future".

Pilot SA is an essential requirement for the operation of a UUV as a lack of SA has the potential to greatly influence the success of operations. Display design becomes

particularly important when considering SA within a complex system such as a UUV due to its potential influence on performance. If a display does not provide a pilot with adequate information in a manner which is conducive to achieving and maintaining a high level of SA, then performance within the system may suffer. It is therefore necessary to experimentally examine UUV display design to ensure it facilitates superior performance.

The current study was based on research conducted in the aviation domain assessing pilot information displays. The aim was to extend on this research assessing its relevance and application to the operation of a UUV.

Conducted as a milestone under task 02/128 Applications of ROV technologies and also, in conjunction with the Department of Psychology at Monash University, the present study sought to investigate the effects of different user interface designs on Unmanned Underwater Vehicle pilot performance. A simulation program was specifically developed for this study which enabled participants to take part in a remote piloting experiment. Participants were asked to fly three simulated missions, each time presented with one of three display designs; a design analogous to the current Mine Disposal Vehicle (MDV) Baseline display, a display developed based on the Inside-Out (fixed vehicle) principle of display design, and a display developed based on the Outside-In (moving vehicle) principle of display design. During each condition, SA and human performance measurements were taken.

Data was analysed using a standard Analysis of Variance approach coupled with post-hoc tests in order to determine the presence and strength of any relationship between display design and pilot performance. Results indicated a significant relationship between display design and level of situation awareness and human performance on a number of measures indicating that UUV pilot situation awareness and performance can be enhanced by modifying and improving pilot display design. Results of this study have implications for the use of unmanned vehicles in the wider air and land domains, as well as continued application in the underwater domain. The results of this study will be discussed in full in this report.

Authors

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Sarah-Louise graduated from The University of Melbourne with a Bachelor of Science (Psychology) in 2001. In 2003, Sarah-Louise completed a Master of Science and Technology in Aviation at the University of New South Wales. In August 2005, Sarah-Louise completed a Post Graduate Diploma in Psychology (Human Factors) with Monash University. Since joining DSTO in 2002, she has been involved in the research of Human Factors issues within the maritime environment. Her work has included the investigation of crewing for future Navy acquisitions, personnel fatigue and performance issues associated with crewing a naval platform and investigation of the effects of display design on unmanned underwater vehicle pilot performance.

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Professor Tom Triggs is associated with the Monash University Accident Research Centre (MUARC), where his research focuses on human factors and road safety. Formerly, he was Director of the Battelle Human Factors and Organizational Effectiveness Research Centre in Seattle, and Manager, Experimental Psychology Department at Bolt, Beranek and Newman in Boston.

He was previously a member of the editorial board of Safety Science, and a member of the U.S. Transportation Research Board Sub-committee on driver training. His current research interests are in human factors of decision-aiding, human-computer interface issues and driving simulation. He obtained his Ph.D. in Psychology from the University of Michigan and his Master's degree in Aeronautical Engineering from the University of Sydney.

Professor Triggs is a Fellow of the Human Factors and Ergonomics Society, and a Fellow of the Ergonomics Society of Australia of which he is a Past President. His research interests are in the areas of human decision making, human factors in transportation, and attentional processes. At MUARC, he is involved in research related to young drivers, in particular, and to the use of simulation in the evaluation of driving performance.

Contents

Glossary

ANOVA	Analysis Of Variance
GDTA	Goal Directed Task Analysis
HCI	Human Computer Interface
HF	Human Factors
HP	Human Performance
HSD	Honest Significant Difference
HSI	Human Systems Integration
HUD	Head Up Display
MDV	Mine Disposal Vehicle
RAN	Royal Australian Navy
ROV	Remotely Operated Vehicle
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SCERH	Standing Committee on Ethics in Research Involving Humans
STAR	Science & Technology Activity Review ethics team
TRANSOM	Training for Remote Sensing and Manipulation
UV	Unmanned Vehicle
UAV	Unmanned Aerial Vehicle
UUV	Unmanned Underwater Vehicle

1. Introduction

Designing an operator display for the operation of a UUV requires close consideration of many human factors issues. Display design is of particular importance in UUV operations as it has the potential to influence pilot performance and degrade mission effectiveness. UUVs are distinctive in terms of their operation as essentially, they are operated from a location external to a pilot's present position. Due to the complexity of operating this type of vehicle, special consideration needs to be made when assessing pilot information requirements, and the subsequent design and presentation of information displays.

From a human factors perspective, the study of display design is not novel. Much research has been conducted in the aviation domain examining pilot display designs [1-8] with the intention of improving system – both man and machine – performance. However, these studies have been conducted for the purpose of application to piloted aircraft, not unmanned aircraft. While a number of studies have been conducted for Unmanned Air Vehicles (UAVs), they have tended to focus on system technologies [9-12] largely neglecting to address critical human factor issues. A small amount of UAV human factors research has been conducted by the United States Air Force examining the operator workstation for the Global Hawk UAV however, this research has not specifically addressed issues associated with operator display design [13].

In contrast to UAVs, UUVs have enjoyed little to no human factors research, particularly with reference to display design. Currently, UUV pilot displays have been developed and implemented principally favouring a numerical format which is by no means ideal [14]. As minimal research into display design exists in the UAV domain, and as UUVs operate in a vastly different environment, it is necessary to consider display design issues as they pertain to the operation of this class of vehicle in their own right [13].

Like their air counterparts, UUV pilots require particular information to perform their job effectively. The ultimate goal of any unmanned system is to provide a pilot with the capability, via the use of sensors, to act and perform as if he or she was really present at the remote location [15]. In support of this, it is necessary to have correct and relevant information to aid completion of an operational task [16]. Information such as; pitch, roll; heading; depth; speed and vehicle location can be considered critical to the task at hand and as such, pilot operator displays must present this information in a manner which is precise, accessible and easily interpretable. The integration and presentation of vital information helps provide an overall understanding to the pilot of their position within the context of their operational environment. This understanding can be described in terms of a pilot's level of Situation Awareness (SA). As a concept, situation awareness describes "the perception of elements in the environment within a volume of time and space, comprehension of their meaning and projection of their status into the future" [17, 18].

Pilot situation awareness is an essential requirement for the operation of a UUV as a lack of SA has the potential to greatly influence the success of operations [19]. Display design becomes particularly important when considering SA within a complex system such as a

UUV due to its potential influence on performance. If a display does not provide a pilot with adequate information in a manner which is conducive to achieving and maintaining a high level of SA, then performance within the system may suffer.

The effectiveness of a display can be measured by a pilot's level of SA and subsequent human performance. While SA is included under the broader heading of human performance, it can also be considered a separate measure which can be correlated against other performance measures. In many socio-technical systems, different aspects of human performance, such as time on task and accuracy, can be measured directly from system data output. An operator's level of SA can be determined through a measure of SA and correlated against actual system data to get a feel for how SA affects different aspects of performance. Human-in-the-loop simulation provides the opportunity to evaluate display design with a view to determining display components that enhance SA and improve pilot performance [19]. The present study sought to investigate ways to display information to pilots that would enhance SA and improve pilot performance.

1.1 Inside-Out and Outside-In Display Design Principles

Piloting a UUV can be a very difficult task. Pilots have to be sufficiently skilled to operate the vehicle to a performance level that is commensurate with actually being on the vehicle. So when considering the complexity of UUV operations, the pilot's frame of reference becomes important in determining how to display critical information.

Consider the example of display symbol motion. When determining the most appropriate way to display information to a pilot, it is necessary to address the question of whether they perceive the display as representing their vehicle moving within the external world, or whether they perceive the external world as moving around their vehicle. These two basic movement relationships can be described as an *Inside-Out* (egocentric or vehicle referenced) frame of reference; or an *Outside-In* (exocentric or world referenced) frame of reference; the difference being whether the vehicles co-ordinates are used as the reference system, or the earth's coordinates are used [20]. Both these frames of reference are used within the aviation domain to display information to pilots [21].

An Inside-Out display design describes the frame of reference typically used in most aircraft displays [21]. Most commonly, the term Inside-Out refers to the depiction of pitch and roll information. An artificial moving horizon display is used which lines up with the horizon that a pilot views while looking straight ahead. When a pilot banks a plane right, the artificial horizon rolls to the left mimicking the motion of the true horizon (Figure 1). With this design, a small aircraft or vehicle symbol remains stationary in the middle of the display and is used as a reference point. The same relationship also applies to information relating to climbing and descending, with an aircraft's pitch information typically displayed by a pitch ladder which indicates the aircrafts position above or below a given point. This moving horizon symbology is approved by the Federal Aviation Administration and is a recognised international standard by most nations [7, 21].

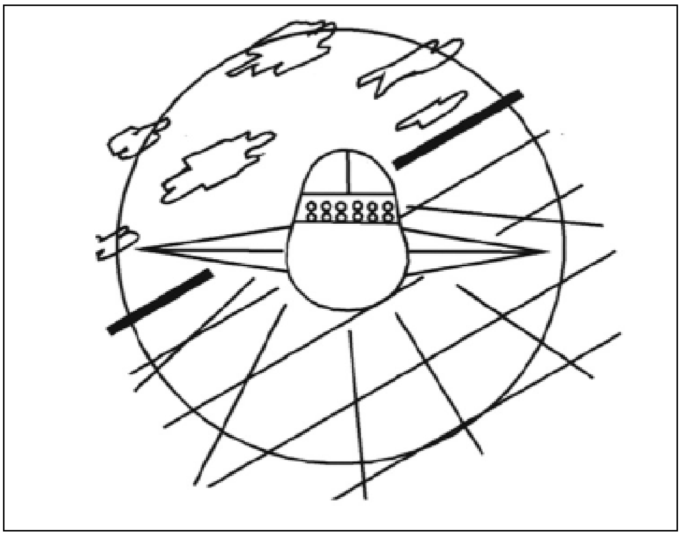

Figure 1: Inside-Out depiction of roll [20]

In contrast, an Outside-In design describes another frame of reference which can be adopted to display aircraft information to a pilot. This display is used most by countries who fly with Russian-built aircraft [21]. The Outside-In or moving aircraft display typically depicts roll information directly opposite to that of the Inside-Out approach. In the Outside-In display, the horizon remains stationary in the display case while a miniature aircraft symbol rolls within the display (Figure 2). When a pilot banks a plane to the right, the miniature aircraft rolls to the right accordingly. The Outside-In display also displays pitch information using a type of pitch ladder. Various researchers have reported that the Outside-In display tends to be more intuitive than the moving horizon display as it mimics stick input and therefore may cause fewer control-reversal errors [22, 23].

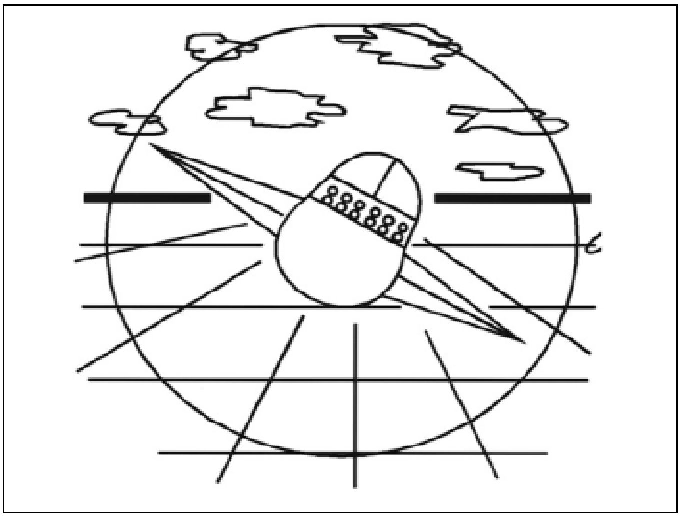

Figure 2: Outside-In depiction of roll [20]

Essentially other information relevant to a UUV pilot, such as depth and heading, can also be displayed to the pilot in either an Inside-Out or Outside-In manner.

Information on vehicle depth can be displayed in an Inside-Out manner using a fixed pointer-moving scale representation. In contrast, this information can also be displayed in an Outside-In way with a fixed scale-moving pointer display. Heading information can also be displayed in a similar fashion with information being vehicle referenced or world referenced (Figure 3). The costs and benefits associated with each design become visible when assessing the level of performance and SA that pilots can achieve.

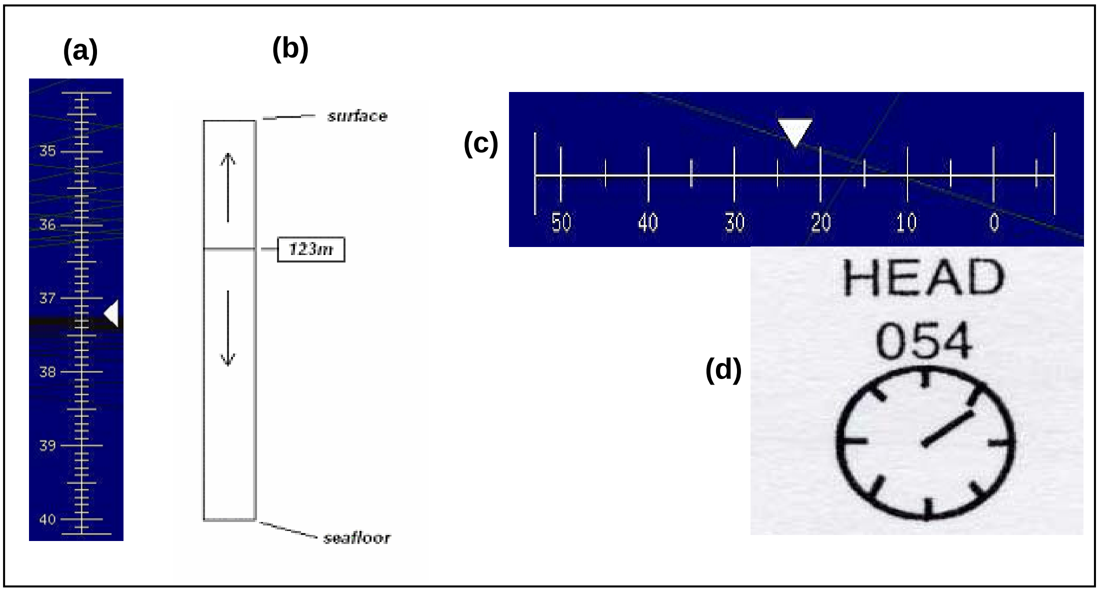

Figure 3: Two principles for displaying vehicle information and the resulting display depiction: (a) Inside-Out or fixed pointer depth display; (b) Outside-In or moving pointer depth display; (c) Inside-Out or fixed pointer heading display; (d) Outside-In or moving pointer heading display

The Outside-In design concept has been the subject of much interest and research comparing its capabilities relative to Inside-Out displays. Most of this research was conducted prior to the 1970s as described in an extensive review article by Johnson and Roscoe (1972) and supports the use of these displays in the aviation environment. Nevertheless, Inside-Out displays have continued to be used extensively in the aircraft used in the Western world up until the present day.

The current study is based on research conducted in the aviation domain assessing pilot information displays [22]**.** The aim was to extend on this research and assess its relevance and application to the operation of a UUV. The present study sought to investigate the effects of display design on UUV pilot performance. Additional literature in the aviation domain has demonstrated the relative influence of display design on situation awareness and human performance [24-26]. In line with this, the current study aimed to examine different frames of reference for displaying information to pilots of unmanned underwater vehicles hypothesising Display Design will influence a pilot's level of SA with the Outside-In design facilitating higher levels of SA. It was also hypothesised that Display Design would affect the performance measures of the number of control reversal errors, number of waypoints reached and the total distance travelled with the Outside-In design again facilitating superior performance over the remaining displays. The results of this study will be discussed.

2. Experiment

2.1 Method

2.1.1 Participants

Participants in the study were 26 individuals recruited from the Royal Australian Navy's Mine Warfare Faculty and the Defence Science and Technology Organisation. The sample included experienced Unmanned Underwater Vehicle and fixed wing aerial pilots, as well as flight naïve participants. The data obtained were representative of 23 Males and 3 Females who ranged in age from 23 to 63 years, contributing a mean age of 39.76 years and a standard deviation of 11.29 years. Participants took part in all three of the experimental conditions and participation was on a volunteer basis.

2.1.2 Materials

The experiment was conducted via the use of a computer simulation program specifically developed for this study. This program was developed extensively over a two year period. For information on the development of this program, please contact the first author.

The simulation program ran on a Pentium 4 – 1.80GHz Dell Laptop computer. The laptop computer was under the control of the experimenter who was present for the running of the experiment. The laptop was connected to an external SAMPA colour monitor (48.26cm diagonal measurement) that sat in front of the participants, and which they used to view the displays in each of the experimental conditions.

Participants controlled a simulated UUV with a joystick that allowed six degrees of freedom. The joystick, which was attached to the laptop computer, was situated in front of the participants colour monitor and was used to control the movements of the vehicle (information on joystick control is provided in Appendix A). Figure 4 shows the experimental setup.

Figure 4: Experimental set up

Human performance and situation awareness data were collected. Human performance data were collected and logged directly by the simulation program. Situation awareness data was also collected electronically through the simulator which incorporated the Situation Awareness Global Assessment Technique (SAGAT) [18, 19] which is designed to question an operator's level of situation awareness. The SAGAT queries were developed following the completion of a Goal Directed Task Analysis (GDTA) [27]. A comprehensive explanation of the SAGAT and GDTA will be provided in the procedure section of this report with further information located in the relevant appendices.

2.1.3 Procedure

Prior to the design and commencement of this experiment, significant preliminary work was conducted which included conducting a number of interviews and focus group sessions with experienced UUV pilots. The interviews and focus group sessions were conducted over one day at the Royal Australian Navy's Mine Warfare Faculty at HMAS Waterhen, Sydney. The day involved conducting a focus group discussion session with experienced UUV pilots. Seven Navy UUV pilots (each with more than a years operational flight experience) attended and took part in discussions on what constituted a 'typical' mission. Upon gaining consent from all involved, the session was tape recorded for coding and data analysis purposes following the focus group. The session lasted for 4 hours and during the focus group, pilots were prompted with a number of open ended questions (Appendix B) which were designed to generate discussion on what comprised a typical mission, and situation awareness information requirements that were considered critical to the successful completion of a mission. Discussions assessed relevant goals and sub-goals associated with successfully conducting a mission. Situation awareness requirements were then determined based on what information pilots considered both essential and relevant to be able to conduct their task and achieve the overall mission goal. The proceeding interviews involved a one-on-one meeting between the researcher and individual UUV pilots to further flesh out situation awareness requirements as related to display design. The interviews which lasted 30 minutes each, were written recorded (upon obtaining consent) and included a component of time using the Navy's UUV pilot training simulator to help further describe and demonstrate information requirements related to achieving situation awareness. Due to time constraints placed on the availability of UUV pilots, only 4 of the 7 pilots were interviewed.

The information obtained during the focus group sessions and one-on-one interviews directly contributed to the conduct of a GDTA which helped generate a UUV mission analysis and information requirements document (Appendix C). The GDTA determined pilot information requirements associated with achieving and maintaining a high level of situation awareness and performance.

The content of the focus group and interviews is not provided in full in the current report rather, information gleaned from the session relating to the determination of generic pilot situation awareness requirements is provided in Appendix C. The three displays used in this experiment were developed as a result of the GDTA conducted.

2.1.4 Experimental Process

In order to compare the display designs, participants were asked to take part individually in a simulated flight experiment in which three different scenarios were presented to each participant. The scenarios were designed to test several aspects of an operator's level of situation awareness and performance. Each of the three scenarios was designed to generate data that would allow a comparative evaluation of the UUV operator displays. Flight data from the simulator were recorded in a log for each participant in each of the three scenarios. The data collected provided information on the operator's level of situation awareness and performance. For each scenario, participants performed with a different display design. The presentation order of the three displays was randomised across the participants. As the experiment sought to determine display design concepts which promoted SA and performance, rather than being an experiment specifically addressing issues of navigation and task difficulty, the presentation of the flight scenarios was not randomised with the presentation of display designs. This decision was justified on the grounds that each of the three flight scenarios were of equal difficulty; the same terrain was used for each scenario, only the starting point varied.

The terrain used for this experiment comprised of data supplied by the Navy's Hydrographic Office. The coastal region was selected due to the variability in underwater features in line with training requirements as determined by the focus group session and interviews. This region permits pilots to operate a vehicle in full six degrees of freedom. The region selected for inclusion in the scenarios was very large (1000m × 1000m) however, participants did not utilise the full area rather operated in a small section. The same section of terrain was used for all three scenarios, only the starting point differed.

A number of waypoints were placed at various locations within each scenario. Participants needed to utilise the instruments and information provided to them via their operator display in order to navigate through the series of waypoints. Each of the operator displays was designed to help pilots gain situation awareness and enable them to sufficiently manoeuvre the vehicle towards each of the waypoints.

All participants received the same instructions and the same three simulated flight tasks. None of the test group was familiar with any aspect of the simulator prior to taking part in the experiment. Ethical clearance was sought and granted from Monash University's Standing Committee on Ethics in Research involving Humans (SCERH) and DSTO's internal STAR team. As an ethical requirement, participants received an explanatory statement (Appendix D) to read and a consent form (Appendix E) to sign.

Participants were given a five minute session to familiarise themselves with joystick controls prior to commencement of the experimental conditions. Participants were provided with a description of the joystick controls (Appendix A) for use during the practice session. They were instructed to read through the instructions and become familiar with the joystick's movements. Once they had finished reading through the instructions, each participant was given a 5 minute practice session with the simulator engaged to familiarise themselves with the joystick and vehicle movements. The simulation program was loaded and participants were permitted to fly around within the simulated environment however, during this 5 minute practice session, no flight instruments were displayed.

At the conclusion of the 5 minute familiarisation session, participants were given a description of the task they were asked to complete (Appendix F). The experimental task required participants to fly to a set of waypoints which were represented on a chart located in the top right hand corner of their operator display. Participants used the instruments and information provided to them on their operator display along with verbal instructions from the researcher in order to manoeuvre the vehicle towards the waypoints. Once participants had read the task description, the experiment began. The researcher initiated the first of the three flight tasks. Using the simulation environment, participants were asked to fly a mission using information provided to them both verbally by the researcher, and visually by their operator display. Participants were required to follow an initial heading provided by the researcher in order to progress towards each of the waypoints. Participants flew towards each waypoint verbally acknowledging to the researcher when they established visual contact with the waypoint as seen through the vision on their operator display. They were then required to fly through the waypoint. When participants acknowledged visual contact with the waypoint, the researcher provided a relative heading to the next waypoint. Participants were instructed to commence along that new heading and make adjustments where necessary to reach that waypoint. The vehicle was restricted to travel below the water surface so reaching waypoints required the operator to navigate around and/or over underwater objects in order to reach each waypoint.

2.1.5 Display Design

Display designs were developed using principles from the aviation domain. Two of the displays were based on the Inside-Out and Outside-In design principles. The Baseline display that was used (Figure 5) is analogous to the display currently in use by the Royal Australian Navy for the Double Eagle MKII Mine Disposal Vehicle. The second display design (Figure 6) was developed based on applying the Inside-Out design principle and the third display (Figure 7) was developed based on applying the Outside-In design principle. Each of the three missions presented a different display design for the operator to use.

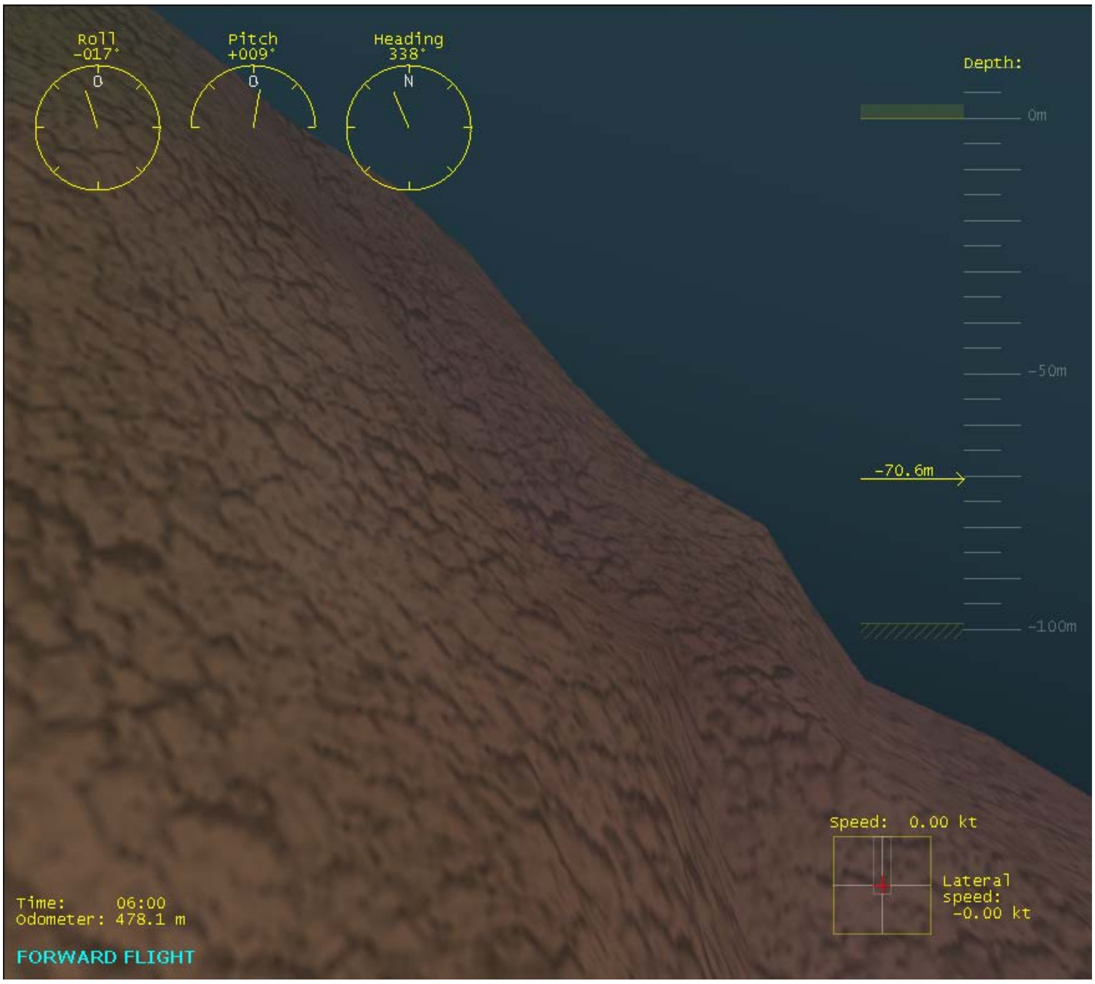

Figure 5: Baseline display design presented with flight task 1

Figure 6: Inside-Out display design presented with flight task 2

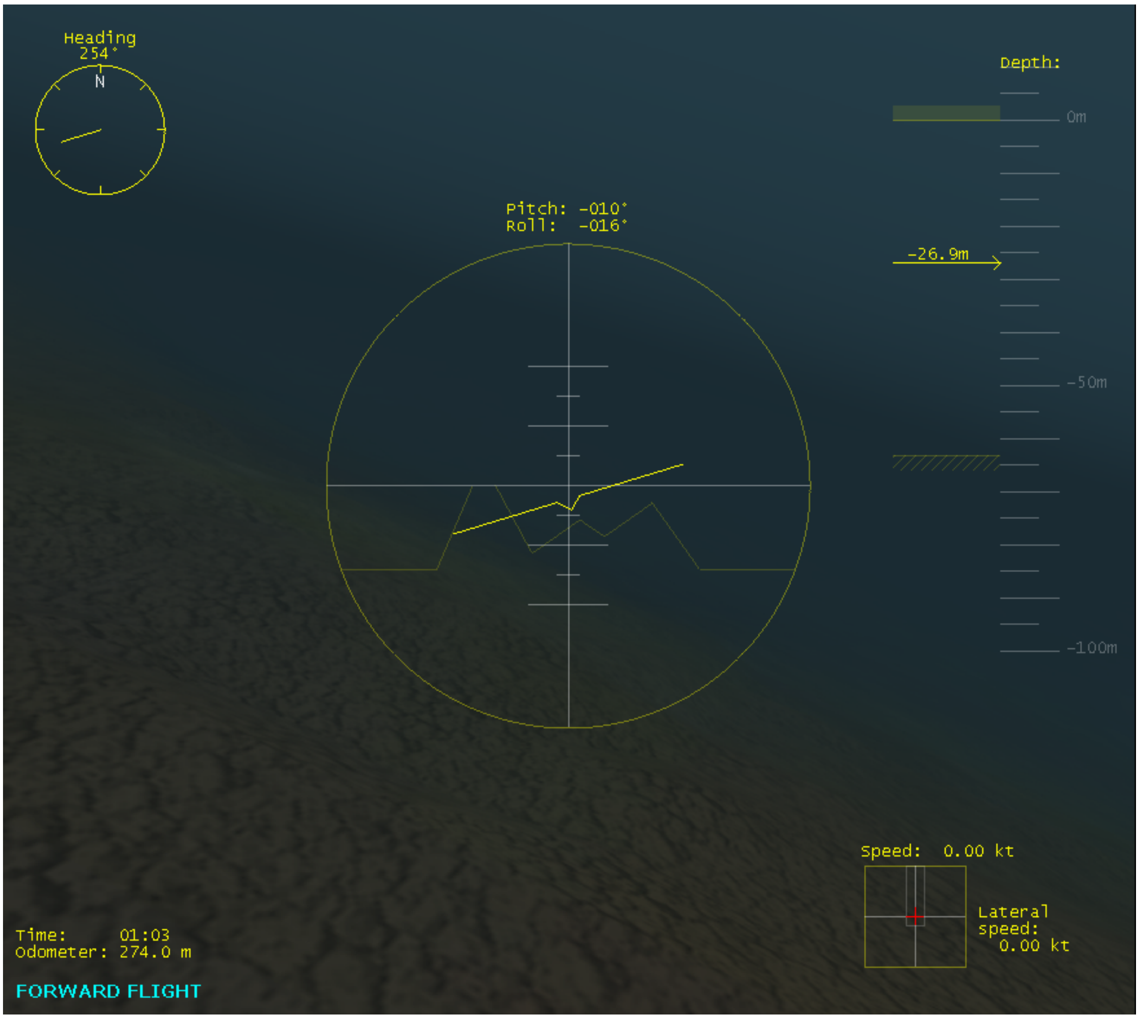

Figure 7: Outside-In display design presented with flight task 3

The three display designs were presented to participants in random order to minimise any systematic effect of learning. On each occasion, the three displays were presented with the same flight task, only the order of their presentation varied.

The chart in the top right hand corner of the screen was used as a navigational aid to indicate when a participant was near a waypoint. Waypoints become visible on the operator's central display when the participant was within 200m range and when the circular vehicle indicator on the reference chart overlaid the red cross which depicted the waypoints (Figure 8).

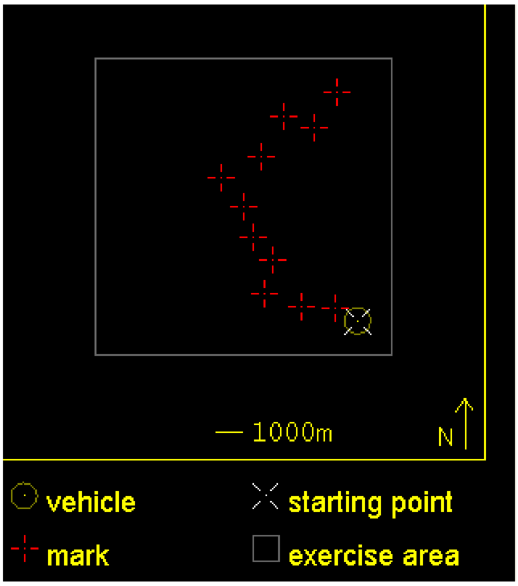

Figure 8: An example of the reference chart used for flight task 3

The circular vehicle indicator overlaid the red waypoint cross as participants approached the waypoint. Participants were able to see waypoints which were represented by large orange diamonds within each scenario (Figure 9), upon approach if the circular vehicle indicator overlaid the red cross slightly. Waypoints were not necessarily positioned on the sea floor, they were also located in the water column above the vehicle.

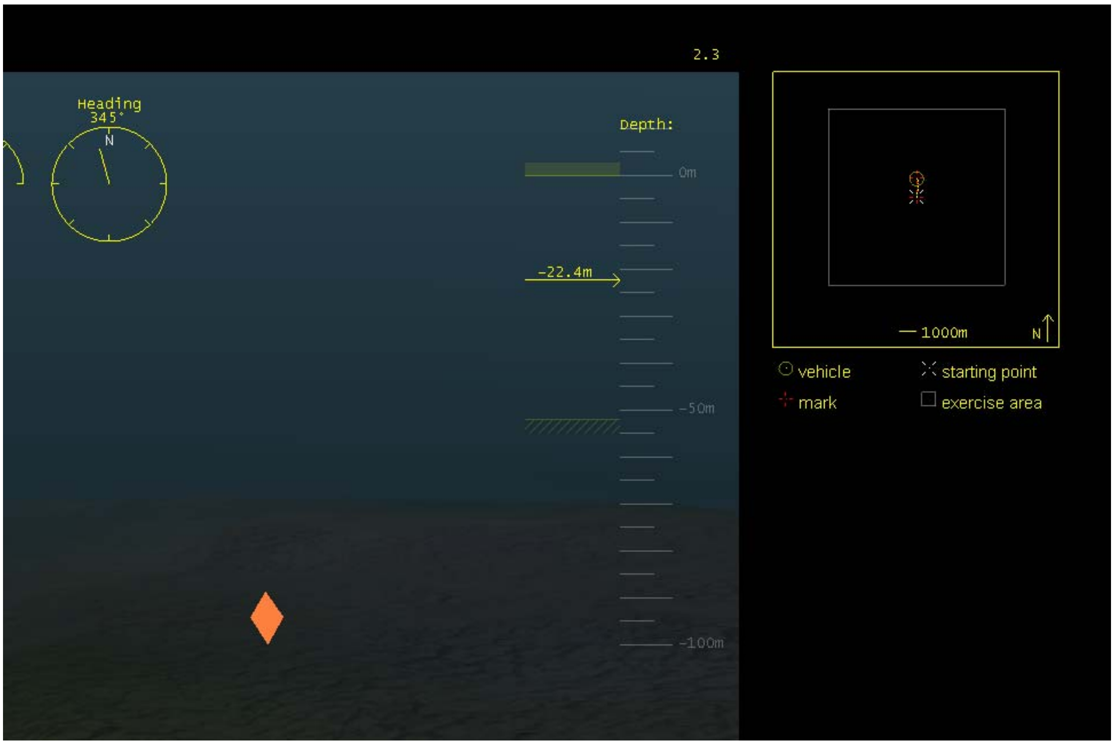

Figure 9: Example of a waypoint as seen visually, and on the reference chart in each scenario

2.1.6 Situation Awareness and Human Performance Measures

In order to assess a participant's level of situation awareness, at random intervals during each flight task, the simulation was paused, the screen was blackened and participants were prompted by a series of questions designed to assess their awareness of the situation at that moment (Table 1). The simulation was paused a total of eleven times for each scenario ensuring all questions were asked. The questions asked were designed to probe all levels of the pilot's situation awareness. Eleven questions were developed in total in accordance with information obtained in the GDTA. Each of the questions was presented in random order and at random times during each display design condition. The timing of the presentation of the questions ensured that no question was asked before 80 seconds had elapsed in each scenario and even then, questions were presented randomly at intervals of between 60 seconds and 75 seconds. This timing ensured that all questions would be asked by the maximum time of 13 minutes and 50 seconds into each of the scenarios. Participants were permitted to fly until 15 minutes had elapsed at which point, the scenarios ended.

The questions were derived from the GDTA which was conducted in order to determine situation awareness requirements for operator displays (information on the GDTA and the development of the situation awareness probe questions is provided in Appendix C). The timing and order of questions was randomised for each experimental scenario to avoid pre-empting or rehearsing answers. All 11 questions were asked during each of the three conditions.

Table 1: SAGAT Queries for UUV remote piloting task

1. Estimate your current pitch angle (in degrees)
2. Estimate your current roll angle (in degrees)
3. Estimate your current speed (in knots)
4. Estimate your current depth (in metres)
5. Estimate your current heading (in degrees relative to north)
6. Estimate the number of the next waypoint you will reach
7. Are you currently accelerating, decelerating or neither?
8. Which direction will you turn in the next 10 seconds (left, right, no change?)
9. Estimate the distance (in metres) to the next waypoint you will reach
10. Estimate the heading required to reach the nearest waypoint
11. What mode are you currently in? (Flight or Hover?)

The situation awareness probe questions related to the instruments and information contained on the operator display and also, where participants were within the environment. In question 11 relating to mode, 'Hover' was defined as allowing the vehicle to maintain altitude and position about or over a place or object. This mode was particularly useful when approaching a waypoint. The vehicle was able to be switched between normal Flight mode and Hover mode which allowed it to manoeuvre differently, hence the requirement for awareness of which mode it was in.

When prompted with a situation awareness question, participants were required to voice their answer to the researcher who then entered it into the question prompt box on their laptop screen (Figure 10). Once an answer was logged, the scenario continued.

SA was measured by the difference between the correct response and the response provided to the SAGAT queries; the smaller the difference between responses, the higher the level of SA for that cue.

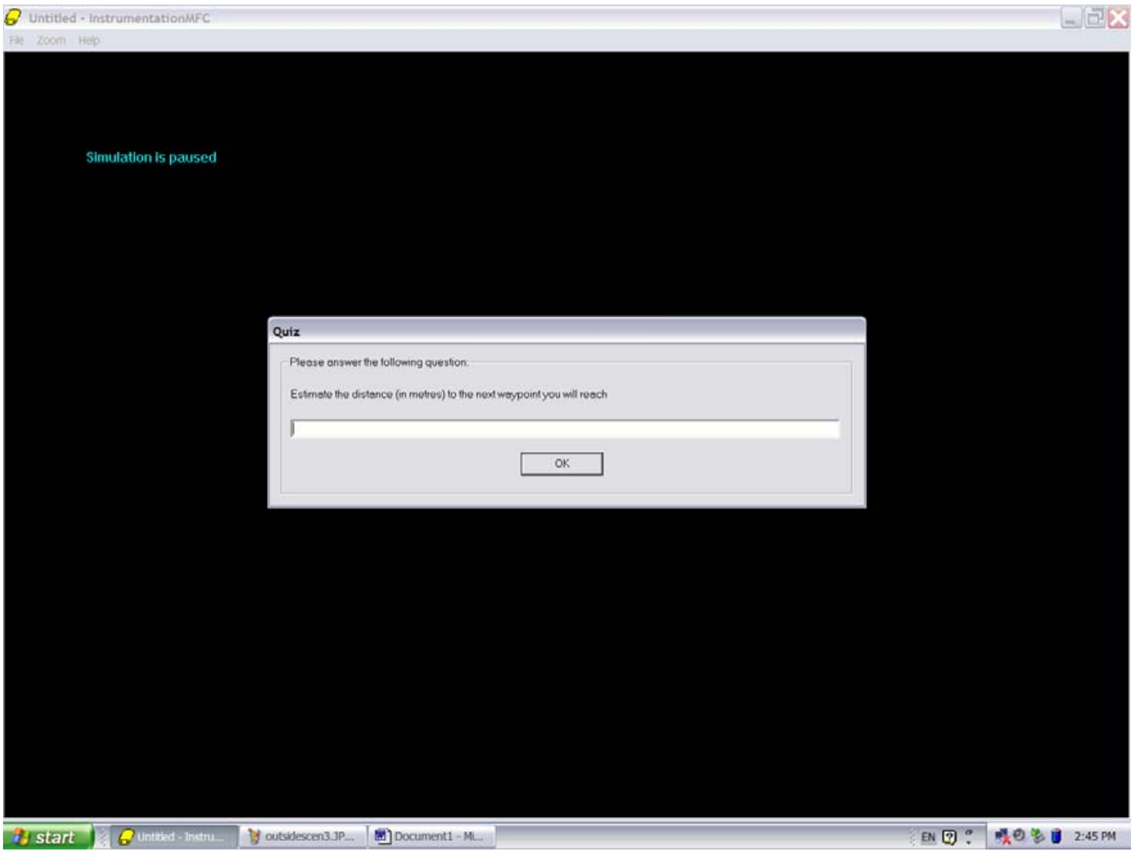

Figure 10: Example of Situation Awareness Question asked during the experimental task

Human performance measurements were also taken during each of the three scenarios. The simulator logged measurements on the number of control reversal errors participants made in each scenario with respect to vehicle roll; the number of waypoints participants reached during each scenario and also, the distance they travelled during each scenario. These measures were used as indicators of performance with respect to the three competing displays. The superior display design was measured by the least number of control reversal errors recorded, the greatest number of waypoints reached and also the greatest distance travelled.

Participants were given 15 minutes to fly each scenario. Scenarios came to an end following the presentation of all SA questions to the pilot. There was a short rest period of one minute between the practice session and each of the experimental scenarios. The vehicle was initially neutrally positioned in terms of pitch and roll, however the initial depth and location within the scenario varied. Participants were advised to keep the vehicle as close as possible to between 10 - 20 metres to the seabed at all times. At the conclusion of all three flight tasks, participants were asked if they had a preference for any of the displays presented and were asked to make comments on each of the three displays presented.

3. Results

The data obtained represent responses given to the SA probes and the performance measurements obtained. The independent variable involved in this study was Display Design. Statistical analyses were performed on the data in order to determine any significant relationship between Display Design and the dependent variables of: level of situation awareness and human performance.

One-way ANOVAs were performed on the data relating to seven of the SA probes and also the performance data. An ANOVA was conducted for each of probes 1 – 6 and probe 10 which related to; pitch, roll, speed, depth, heading, the estimated distance to the next waypoint, and the estimated heading to the next waypoint respectively. SA was measured by the difference between the correct response and the response provided to the SAGAT queries; the smaller the difference between responses, the higher the level of SA for that cue. One-way ANOVAs were conducted on the performance data obtained for: the number of control reversal errors recorded for vehicle roll in the Inside-Out display condition, the number of waypoints reached in each condition, the odometer reading for each condition. A speed profile was also generated for the approach to the first waypoint in each condition. An ANOVA was conducted on the data to determine any difference in approach speed to *Waypoint one*. Superior performance was measured by the least number of control reversal errors, the most waypoints reached, the greatest odometer reading and the display with the highest mean speed upon approach to the first waypoint.

No correction was made for Type I error. Each measure was judged to be largely independent of the others as they measured different aspects of performance.

Based on the results obtained for all participants, comparison was made between the frequency of correct and incorrect answers given to SA probes 7 – 9 and probe 11 which related to: estimated number of the next waypoint; whether the vehicle was accelerating, decelerating or neither; the direction the vehicle would turn in the next 10 seconds; and the vehicle's current mode of operation (flight or hover). Display design conditions that yielded the highest percentage of correct answers were deemed to have provided higher levels of SA for that cue. Participants' display preference was also recorded. A Chi-Square was performed on the data to determine if there was a significant preference for display design.

3.1 Results for Situation Awareness Measures

The ANOVA results revealed a number of significant outcomes.

A significant effect was found for Display Design for the measure of vehicle roll (SA query 2) $F(2, 75) = 4.277$, $p = .018$. A post-hoc Tukey HSD test revealed a significant difference between the Baseline and Outside-In display design conditions for vehicle roll with the Outside-In condition providing a higher level of SA for that cue. These results are shown in Figure 11.

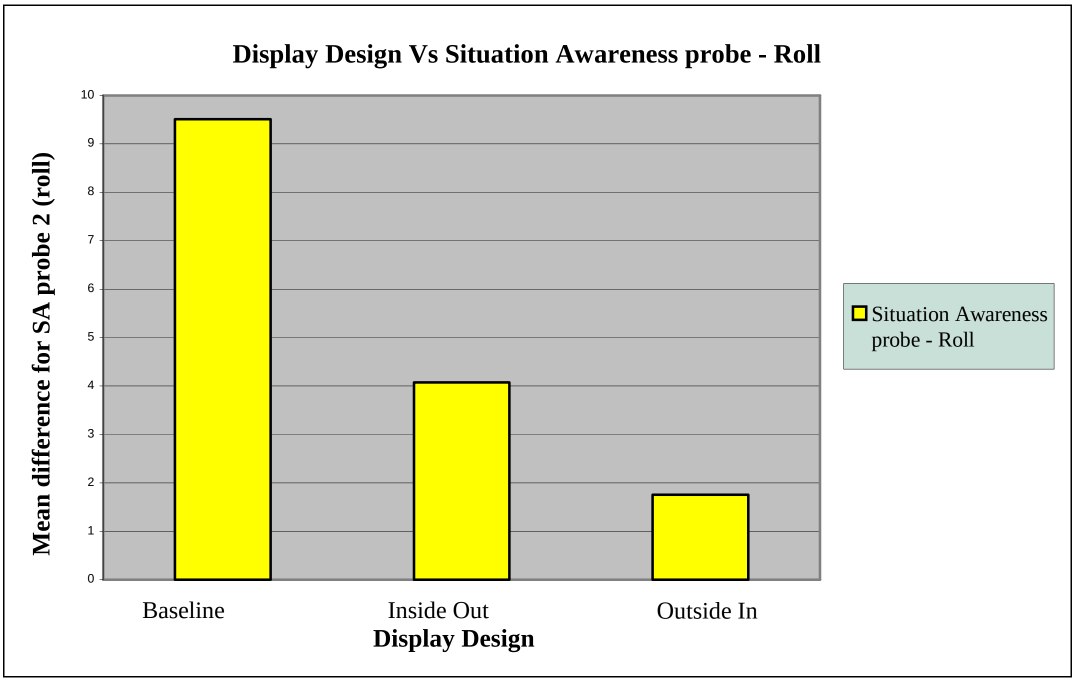

Figure 11: Mean difference between display design for SA probe 2 relating to roll

A significant effect was found for Display Design for the measure of vehicle depth (SA query 4) $F(2, 75) = 3.617$, $p = .032$. A post-hoc Tukey HSD test revealed a significant difference between the Inside-Out and Outside-In display design conditions for vehicle roll with the Inside-Out condition providing a higher level of SA for that cue. These results are shown in Figure 12.

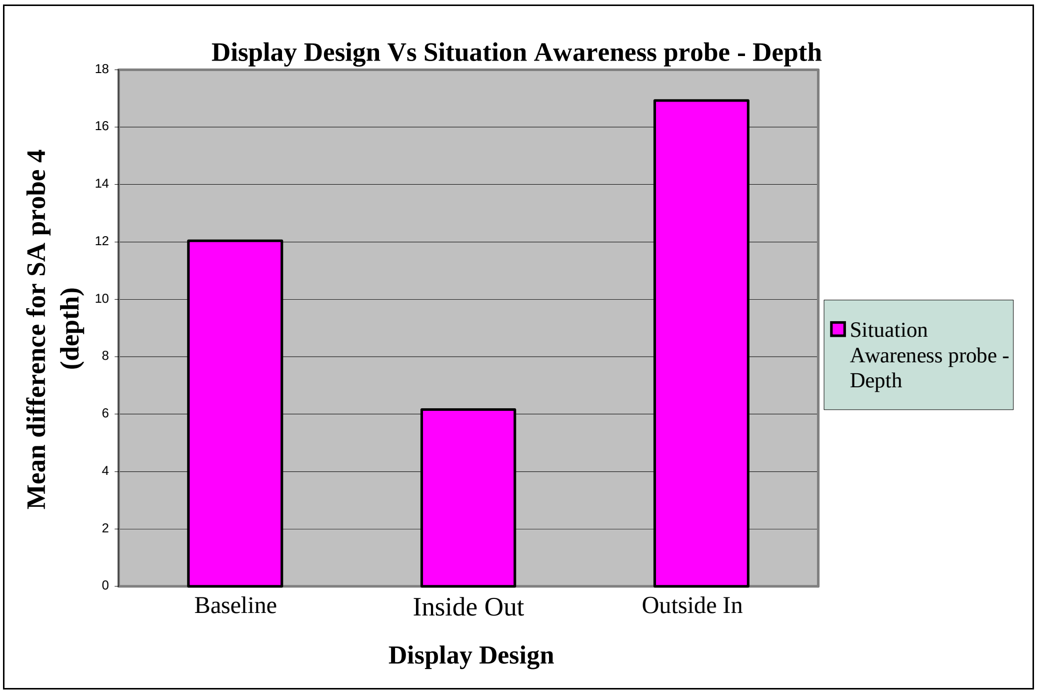

Figure 12: Mean difference between display design for SA probe 4 relating to depth

No significant difference was observed between the Display Design for the remaining SA probe measures relating to pitch, speed, heading, the estimated distance to the next waypoint, nor the estimated heading to the next waypoint.

Based on all participant responses, a comparison was made between the percentage of correct responses given to SA probe 7: Estimate the number of the next waypoint; SA probe 8: Are you accelerating, decelerating or neither; SA probe 9: Estimate the direction you will turn in the next 10 seconds and; SA probe 11: What mode are you currently in? (Flight or Hover?) for each Display Design. The Baseline design recorded the highest number of correct responses for each of these probes, with only the Inside-Out condition sharing an equal maximum highest percentage of 100% for SA probe 11. These results are presented in Table 2.

Table 2: Percentage of correct responses across participants and testing times for SA probes 7 to 9 and SA probe 11 for each Display Design

Question	n	Baseline	Inside-Out	Outside-In
Q7. Number of the next waypoint	26	76.9	76	65.4
Q8. Are you accelerating, decelerating or neither	26	84.6	80	80
Q9. Direction you will turn in the next 10 seconds	26	88.5	80	73.1
Q11. What mode (Flight or Hover) are you currently in	26	100	100	96.2

3.2 Results of Performance Data Measurements

A significant difference was observed between the display designs for the number of control reversal errors observed for vehicle roll $F(2, 76) = 38.235$, $p = .000$, shown in Figure 13. A post-hoc Tukey HSD test revealed a significant difference was observed between each pair of the Display Designs with participants having the least number of control reversal errors for in the Outside-In condition. These results are shown in Figure 13.

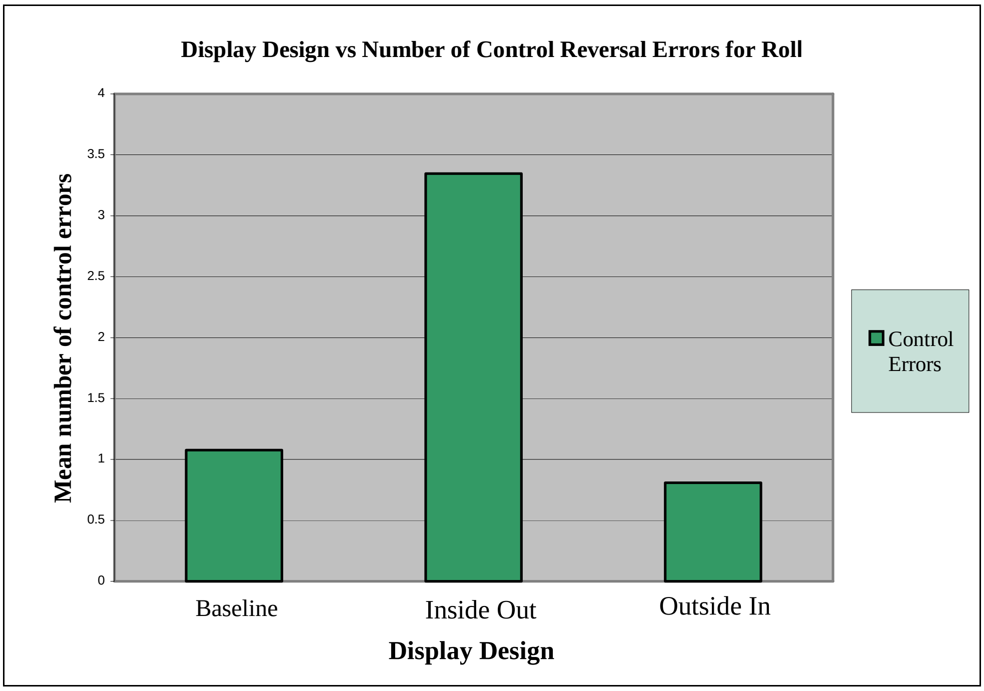

Figure 13: Number of control reversal errors observed vehicle roll for each display design

A correlation was run on the data for the number of waypoints reached and also, the odometer reading. A correlation of r = *.775*, p= *.000* was obtained indicating a significant association between these two measures. These results are presented in Table 3.

Table 3: Correlation between the Number of waypoints reached and odometer reading

Correlations		Number of waypoints reached	Odometer reading
Number of waypoints reached	Pearson Correlation	1	.775(**)
	Sig. (2-tailed)		.000
	N	77	77
Odometer reading	Pearson Correlation	.775(**)	1
	Sig. (2-tailed)	.000	
	N	77	77

** Correlation is significant at the 0.01 level (2-tailed).

A significant difference in the number of waypoints reached was observed between the Display Designs $F(2, 76) = 17.371$, $p = .000$. A post-hoc Tukey HSD test revealed a significant difference was observed between each pair of the Display Designs with participants reaching the most waypoints in the Outside-In condition as shown in Figure 14.

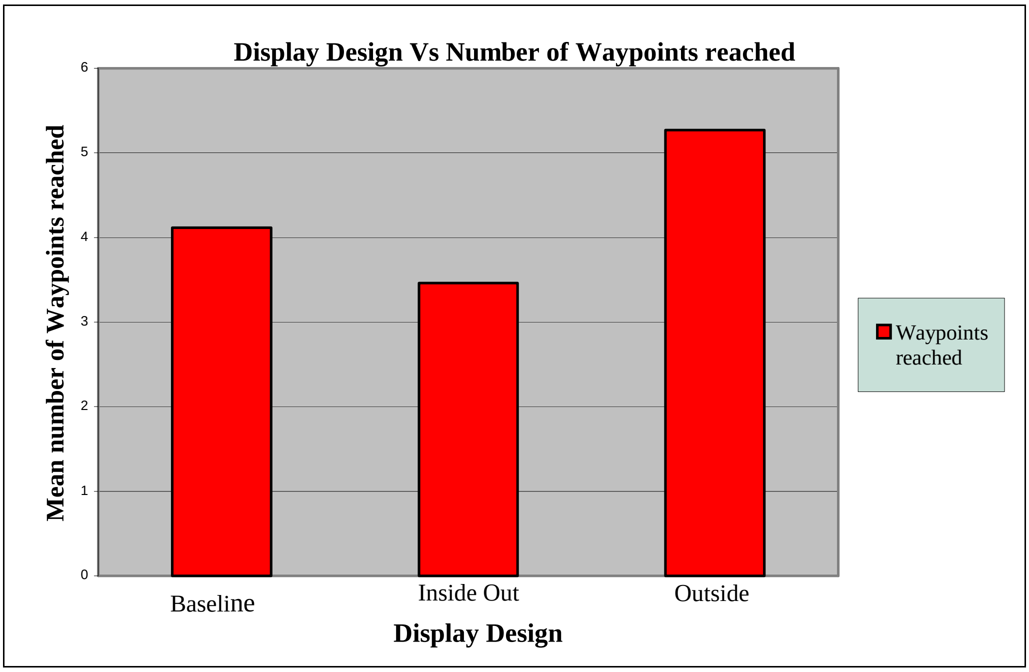

Figure 14: Number of waypoints reached for each display design

A significant difference in odometer reading scores was also observed between the Display Designs $F(2, 76) = 4.483$, $p = .015$. A post-hoc Tukey HSD test revealed that a significant difference was observed between the Inside-Out and Outside-In conditions with the Outside-In condition yielding the highest odometer reading. These results are shown in Figure 15.

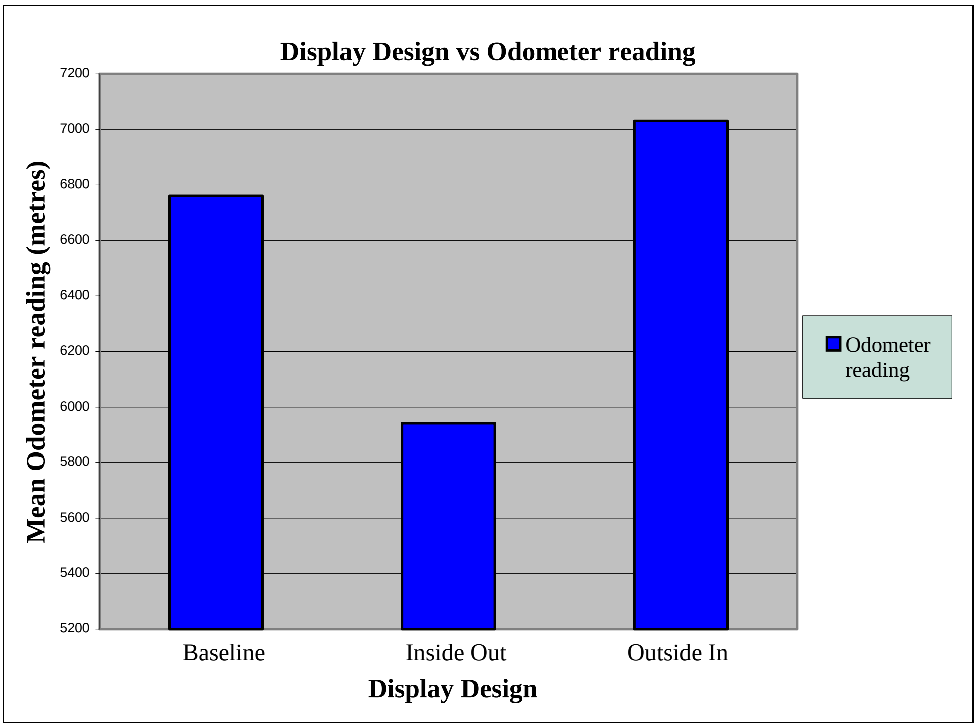

Figure 15: Mean Odometer reading for each display design

A speed profile was generated for the first waypoint in each Display Design condition. *Waypoint one* was selected for inclusion in the analysis as all participants reached it during each of the three Display Design conditions presented. As shown in Figure 16, the speed profile for the Baseline and Outside-In conditions were roughly equivalent while the Inside-Out condition demonstrated a drop in performance with respect to the other two Display Design conditions. A significant difference in approach speed to the first waypoint was observed between all three Display Designs $F(2, 12) = 7.215$, $p = .009$. This ANOVA was run on the value obtained for the mean speed of all participants at the 200m, 150m 100m, 50m and 0m point upon approach to the first waypoint.

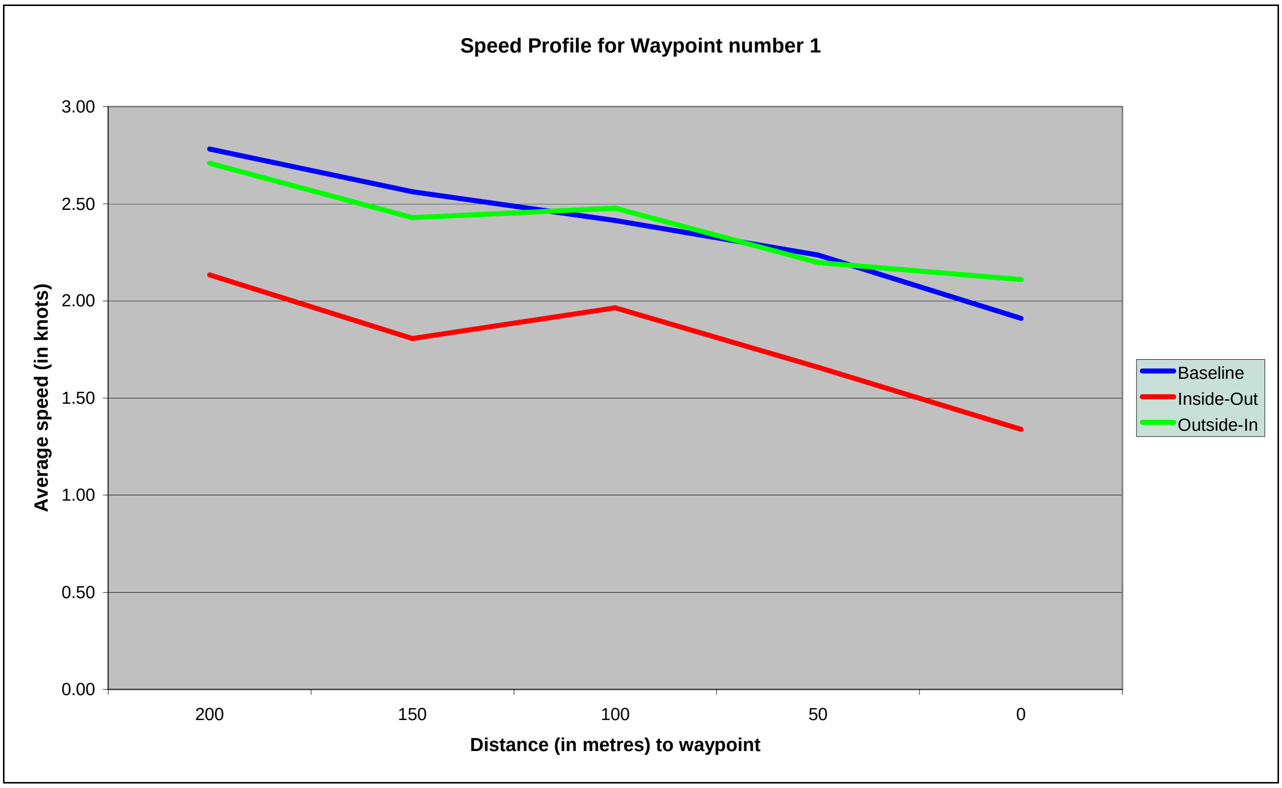

Figure 16: Average speed for the approach to Waypoint one for each display design condition

A Chi-Square was conducted on the categorical data obtained for display preference and Age, Gender and Experience. Participants showed a significant difference in the frequency for preference of display χ^2 (2, n =26) = 18.538, p = .000 with the Outside-In display preferred by almost 75% of participants. This result is shown in Figure 17.

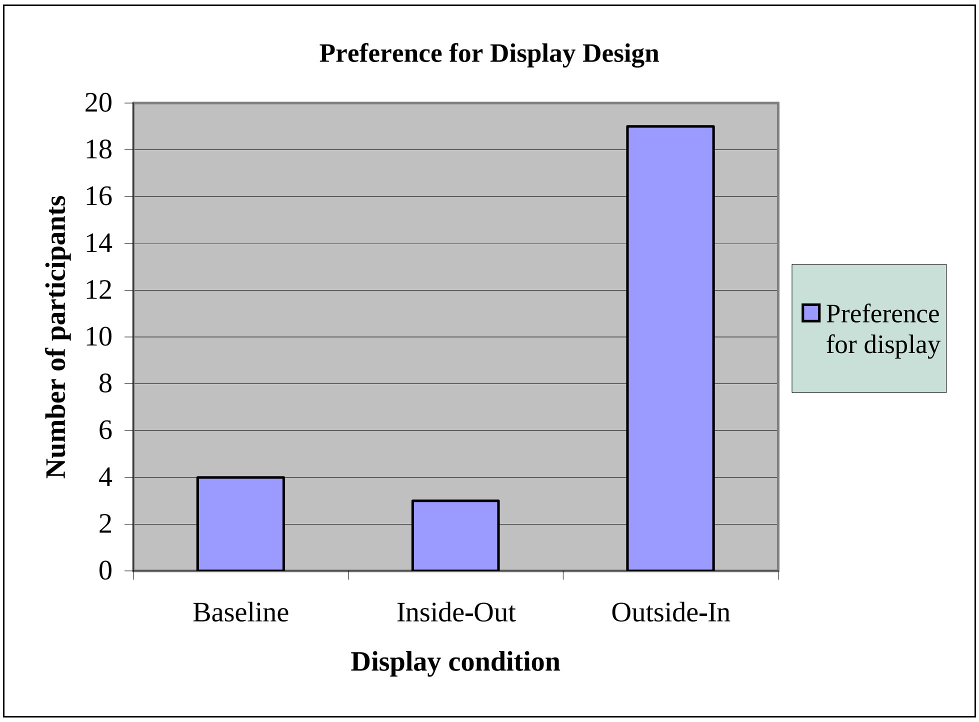

Figure 17: Participants preference for Display Design

In addition, two one-way ANOVAs were conducted on the data obtained for level of experience in years and mode of experience (in terms of fixed wing aerial pilot or UUV pilot) against SA and the performance measures listed. No significant difference was observed for any of these variables.

4. Discussion

The results contained in this study supported the hypothesis that Display Design would influence a pilot's level of SA with the Outside-In providing for comparatively superior performance. The results also supported the hypothesis that Display Design would affect pilot performance in terms of the number of control reversal errors observed, the number of waypoints reached and the total distance travelled with the Outside-In design again facilitating superior performance over the remaining displays.

The results show significant differences were observed between the display types in terms of level of situation awareness for a number of cues. Significant differences were observed between designs for vehicle roll with the Outside-In condition providing a higher level of SA and the designs for vehicle depth with the Inside-Out providing a higher level of SA for that measure. The results also show significant differences between the Display Designs; in the number of control reversal errors observed for roll with the Outside-In condition producing significantly fewer errors than the other two displays; the number of waypoints reached with the Outside-In condition reaching the most waypoints, and also the odometer reading with participants travelling further in the Outside-In condition. In accordance with these findings, results also indicate the Inside-Out display induced worse approach speed to *Waypoint one*.

Results indicate that the Outside-In concept is generally suited for the remote control of a vehicle for a number of reasons. It makes sense to employ an Outside-In concept for these particular displays as the pilots that operate such vehicles are already outside of the vehicle (both physically and psychologically) and the Outside-In format provides the best stimulus response compatibility thus reducing the incidence of control errors.

Interestingly, the results obtained for this experiment both support and contradict previous research findings in the related literature. Whilst in general, the results tended to support previous findings in favour of an Outside-In display concept, some of the results for the SA cues and performance measures were contradictory in nature to commonly cited conclusions with reference to the use of Inside-Out concepts.

Analysis of the data collected for the situation awareness measure for roll provided some interesting results. A significant difference was observed between Display Design for vehicle roll with the Outside-In representation of vehicle roll providing the highest level of situation awareness for that cue. There were significantly smaller errors in roll estimation for the Outside-In condition over the Baseline condition. This observation may be explained by the reduced visual scanning requirement imposed by the Outside-In display condition.

Outside-In displays can be considered beneficial in that they reduce the need for visual scanning between panels by displaying information to a pilot that has already been integrated – such as information about vehicle pitch and roll [25]. This reduces the requirement for pilots to mentally integrate information in order to gain an understanding of their vehicle's current state.

In the Outside-In condition, information on vehicle roll is located centrally on the operator's screen providing an immediate visual representation of the vehicle's current roll state. This information is integrated with information on vehicle pitch thus requiring less mental processing and visual scanning on the part of the operator. The results obtained support previous research findings about information displayed in a non-integrated (separate displays or co-planar) format, such as roll and pitch are in the Baseline display [25]. Presenting information in a non-integrated manner adds a cognitive load to the operator as attentional resources become divided between scanning and subsequent processing of information. This increase in cognitive load results from the requirement to visually scan the instruments, then process and integrate information in order to gain an accurate understanding of the vehicle's current state. An inability to gain an accurate understanding of a vehicle's state within its current operational environment will result in lower levels of pilot SA which has the potential to impact on performance thus reducing efficiency.

The findings support other literature which indicates that contributions of the scanning and processing requirements of non-integrated (Baseline) versus integrated Outside-In displays will impose penalties on operator performance in terms of accuracy and reaction time [28, 29]. A subsequent integrated Outside-In representation of data reduces the cognitive load imposed on a pilot through the reduction of visual scanning and information processing thus providing an observed improvement in situation awareness through gaining a more accurate picture of the vehicle's current state [30].

Another interesting result observed for SA probe 2 relating to vehicle roll was the lack of significant difference observed between the Inside-Out condition for roll and the other two Display Designs despite the very high incidence of control reversal errors for that particular display.

The Inside-Out (egocentric) representation of pitch and roll supports the principle of pictorial realism, since the view is similar to what is seen by the pilot. However, it violates the principle of the moving part [5, 20]. For example, for a pilot to roll the vehicle to the left would require a leftward joystick movement to generate a counter-clockwise rotation of the vehicle. But in doing so, this leftward movement of the control input produces a clockwise rotation of the moving element on the operator's display - the artificial horizon bar - in a way which is counter-intuitive to the pilot's mental model. If the display does not respond in a way that is congruent with stick input and the pilot's mental model, this increases the likelihood of control reversal errors - a reduction in the stimulus-response compatibility [22, 23, 31]. In this study, the Outside-In depiction of roll and corresponding control input does not produce as many control reversal errors as the Inside-Out condition as matching the control motion with the motion of the display preserves the inherent stimulus-response compatibility relationship [32, 33]. These results can be compared to similar findings by Worringham & Berringer (1998) who looked at control response as related to an operator's visual field. They concluded that the field of view and directional stimulus-response compatibility are intimately linked. Fewer control reversal errors were observed when the control motion is in the same direction as the display motion [34]. Similarly, other researchers have found a reduction in control reversal errors in cases where display motion is compatible and congruent with the frame of reference of the control input [25, 35-37]. While there was no significant difference observed for roll between the Outside-In and Inside-Out conditions, in light of the high number of control reversal errors observed for the Inside-Out display, adopting the use of the Outside-In display for roll proves most appropriate.

In addition to producing more control reversal errors, it was interesting to note that the Inside-Out condition did not perform as well on other performance measures as its design counterparts. The Inside-Out performed the least well out of the three designs on the other performance measures in terms of the number of waypoints reached, the final odometer reading and also the speed profile for approach to *Waypoint one*. These findings are not in accordance with literature in the aviation domain which found a significant effect of Display Design and the mean time to traverse all waypoints. In a study conducted by Wickens et al. [29], the Inside-Out display format revealed a clear and predicted advantage for guidance tasks. This result was not replicated in the current study with the Inside-Out condition performing significantly worse that the other displays on the number of waypoints reached. This reduction in performance may be due to the information processing costs associated with this display design. Higher processing requirements on a task generally result in a speed vs. accuracy trade-off, the generalisation is that when speed is of the essence, accuracy will decrease and vice versa, hence there is a trade-off in functioning between them. This may explain the reduced performance in that pilots were devoting so much attention to processing information that they sacrificed speed for accuracy. This would explain why they reached significantly fewer waypoints and did not travel as far on average.

The stimulus response compatibility of the displays has already been cited as an issue which would have the ability to affect overall performance. For participants to travel a shorter distance as recorded by their odometer and thus, reach fewer waypoints during each mission indicates an uncertainty or that they were less comfortable with the display. The speed profile as observed for each of the three Display Design conditions indicated that the approach speed pattern to *Waypoint one* for the Baseline and Outside-In designs was roughly equivalent. Pilots appeared to be able to maintain a constant and higher speed for longer on approach to the waypoint which indicated they were comfortable with workings of the display. The speed profile observed for the Inside-Out condition showed a significant reduction in performance in terms of being able to maintain speed at a constant and high level. As a consequence of this, participants obviously tended to reach fewer waypoints and thus, had lower final odometer readings than the other displays. This result can not be considered a function of the difficulty of the task as complexity was matched overall for all three conditions. This observed reduction in performance for the Inside-Out display has particular implications for mission effectiveness. If the display does not foster improved performance, then mission efficiency will be affected. In reviewing the results obtained for the performance measures for the Inside-Out display, a clear reduction in overall performance is observed thus indicating this type of display is less suitable for enhancing performance for UUV vehicle piloting purposes than the Baseline and Outside-In displays.

The results obtained for the situation awareness measure of depth were interesting. The Inside-Out depiction of a depth counter produced the highest level of situation awareness than the other two Display Designs. The Inside-Out depth indicator was a fixed pointer-moving scale design, similar to that which has been adopted for most aircraft displays relating to altitude [38] while in the other displays, depth was indicated by a fixed scale-moving pointer representation. The results obtained in the present study support the application of the fixed pointer – moving scale design as a suitable way to represent height above or below a given point, as seen with their use in the aviation environment. However, a disadvantage of such displays is that digital values become hard to read when the variable is changing rapidly since the digits themselves are moving. In the aviation environment, this becomes an issue due to the speeds and ease of movement aircraft achieve however, its effects become less of an issue when considering use of this type of display in the underwater environment due to the reduced speed at which these vehicles operate. Coupled with the reduction in speed execution in the operational environment, this particular type of display may also prove superior as it reduces the requirement for visual scanning. The fixed pointer is readily locatable within the operator screen unlike the Outside-In depiction of depth in which the value scrolls up and down the operators screen depending on their relative depth thus increasing visual scanning requirements.

The results obtained for the situation awareness questions 7-9 and 11 relating to the number of the next waypoint; whether the vehicle was accelerating, decelerating or neither; the direction the vehicle would turn in the next 10 seconds and; what mode the vehicle was currently in respectively, indicate that the Baseline display was superior in terms of providing the highest percent accuracy for those cues. While the other displays tended to fare slightly worse, this may be due to the information processing requirements associated with them. Also, the fact that performance on the Outside-In display was higher than the Baseline in terms of number of waypoints reached, it is reasonable to assume that the further a pilot gets into the task, the less likely they will be to remember the number of the next waypoint making that particular cue (for that condition) a memory task rather than a performance task. In short, the more waypoints a pilot reached, the less likely they were to recall how many they had passed through.

In addition to the above analyses, comparison was made on a number of categorical variables to determine if there were any additional influences which could have explained a reduction or improvement in performance. In contrast to previous findings where training novice pilots to master an Inside-Out display took much longer than for the moving aircraft display [13, 39], the results obtained did not support this. In terms of level of experience and mode of experience, the results obtained revealed no difference between Display Design for the level of performance on either the SA or the performance ratings. Novice and experienced pilots (both UUV and fixed wing pilots) performed equally well on each of the display designs. There was also no difference observed between Display Design and performance for age or gender. In spite of the measurable outcomes, participants had a clear preference for the Outside-In display over the other two display conditions.

This study provided a number of interesting results which have implications for both theory and practice when considering display design for remotely piloted vehicles, however a number of limitations were imposed on the current study. While the results of this study are generally encouraging, a number of additional variables could have influenced the results obtained. While some participants were UUV and fixed wing pilots, the majority of the participants were flight naïve participants, some of which had never operated a joystick before. Accounting for outliers in the data, this still may have impacted on results. While flight experience did not appear to have an effect on the level of SA or performance, a certain level of knowledge of display motion and vehicle control mechanisms ought to be assumed due to the nature and complexity of performing such tasks. In hindsight, it might have been advantageous to recruit only flight experienced pilots to participate however, this would have proved very difficult to arrange. A follow-on study aims to further investigate pilot training and experience in greater detail in order to determine any influence of experience with respect to performance on tasks.

The current study provided results which have implications for the wider military community when considering display design for remotely piloted vehicles. A variety of control displays are currently being used for these vehicles, many with deficiencies [14] and research aimed at improving unmanned vehicle control-station design is underway in a number of laboratories. The findings demonstrate that not all the principles of display design employed in the aviation domain are readily applicable to the underwater environment and conclusions drawn from the current study will assist researchers in this area in determining a suitable display design which produces superior performance on all variables.

Whilst this study did replicate a number of results gleaned from the aviation literature, some were in contrast indicating the apparent differences in these operating environments. Noted differences, such as degrees of freedom of vehicle movement, and the speed of task execution in each of the operating environments indicate that assuming universality between the two operating environments is not advisable, rather research for the underwater environment should be conducted in its own right to experimentally determine the nature and relative significance of these differences. In line with this, results indicate improvement in UUV operator situation awareness and performance can be achieved by improving the design of the current operator display. Significant differences were observed between display designs and the level of situation awareness and performance, these differences were observed for; vehicle roll, depth, number of waypoints reached, control reversal errors observed for roll in the Inside-Out condition and the speed profile for approach to waypoints. As a consequence of these findings, a 'composite' display is proposed which encompasses all attributes of the displays that produced the best performance and provided higher levels of situation awareness (Figure 18). The composite display comprises of the Outside-In depiction of roll & pitch, the Baseline depiction of heading and the Inside-Out depiction of depth. In the case of the representation of vehicle heading where statistical significance was not achieved, the attribute representing vehicle heading from the Baseline (Mine Disposal Vehicle) display was retained. While this format for displaying heading was not altered, it is considered an Outside-In display.

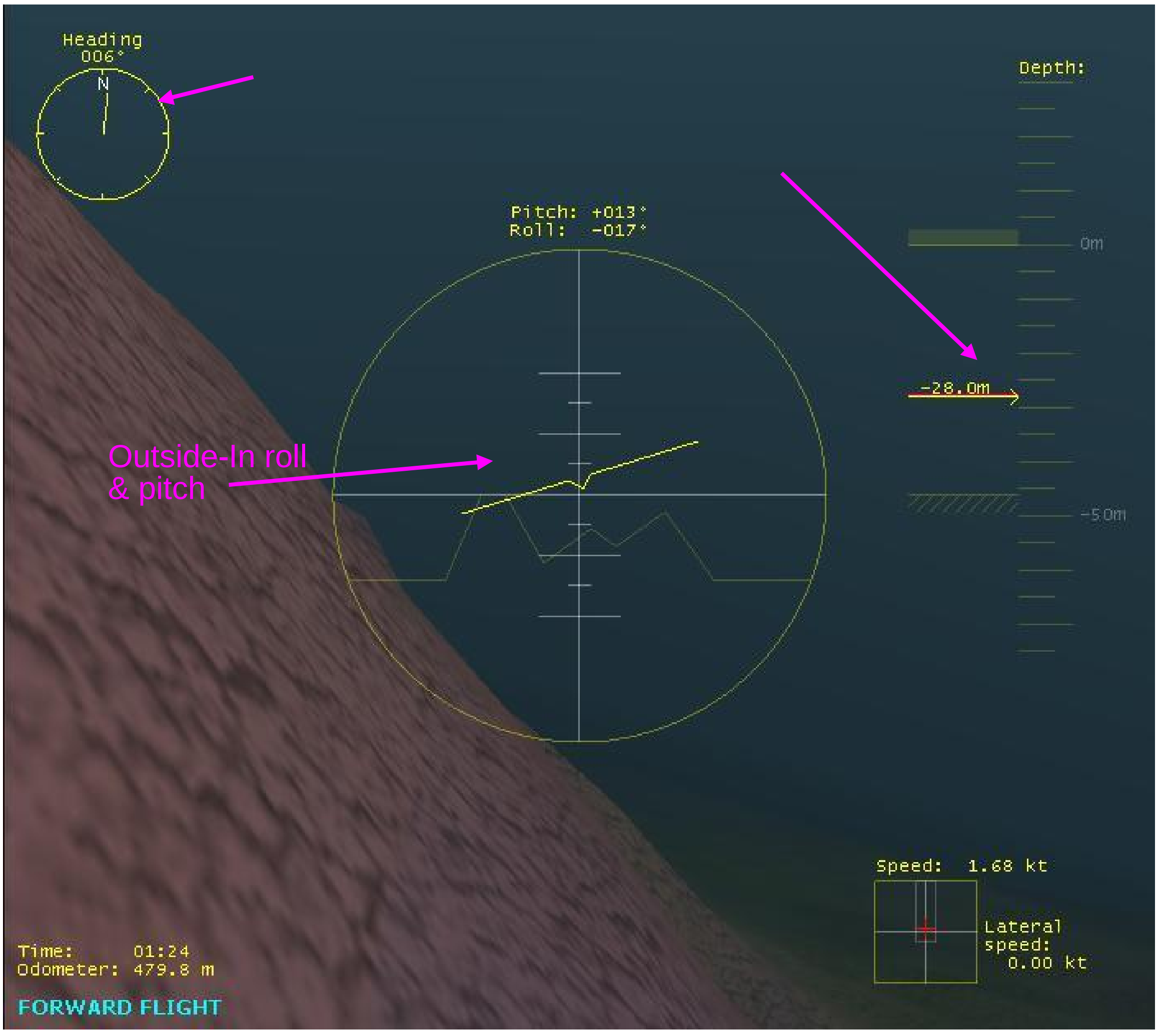

Figure 18: 'Composite' display for enhanced situation awareness and performance

The current findings are encouraging for work on display design for remotely piloted vehicles. As this study is one of the first human factors studies conducted for UUVs, many future research endeavours will follow. A necessary next step is to investigate the effectiveness of the composite display in its entirety in terms of its provision of enhanced situation awareness and performance. To confirm the results obtained in the present study, the composite display should be tested against the current Baseline display to determine overall effectiveness. Implementation of the composite display in the real operating environment will also be a necessary step to ensure its suitability. In addition to this, the control mechanisms through which remotely piloted underwater vehicles are operated need to be investigated. Given the complexity of the environment, and the ability of the vehicle to move in six degrees of freedom, controlling the vehicle can be very difficult. It seems appropriate to investigate the vehicle's current manual control mechanisms in order to determine their suitability for aiding superior performance in conjunction with the use of the proposed composite display (Figure 18). Additionally, pilot training programs and pilot selection criteria should be investigated to see if these variables have any influence on mission effectiveness.

Human factors research for UUVs is a new and exciting domain which presents many research opportunities. As indicated, many issues exist that can combine to influence overall system performance, particularly in the case of a remotely piloted vehicle. When seeking to improve overall system performance, display design becomes a very important issue as it has the ability to influence situation awareness and performance. In summary, the results of the current study tended to support similar research findings in the aviation domain. However, some discrepancies between the operating environments are noted, such as the degrees of freedom of vehicle movement and the speed of task execution contrasting the two environments. Results indicate situation awareness and pilot performance can be improved through the investigation of Display Design, a result which has implications for human factors studies into the operation of unmanned vehicles right around the world.

5. Literature Review

Over recent years, Unmanned Vehicles (UVs) have emerged as a sensible and practical alternative to human involvement in many situations. As such, these vehicles have been embraced by commercial and military establishments around the world. Increasingly, UVs of all forms are taking on roles, particularly in the military environment, where the risk to human life is considered too high or where environmental conditions are too inhospitable for humans [40].

In today's technological environment, many different types of transport UVs exist and are utilised for a wide range of purposes. By far the most prominent in this family are the unmanned air and ground vehicles and as such, much of the research into UVs has focused specifically on these arms of the family with interests mainly confined to system technologies [9-12]. An emerging maritime equivalent also exists, the Unmanned Underwater Vehicle (UUV) which now plays an important role in underwater operations. While the UUV is recognised as part of this family, they have not been subject to the same level of research as their air and land counterparts. To that end, the UUV - or Remotely Operated Vehicle (ROV) as they are also known - can somewhat be considered a new class of socio-technical system.

The human element plays a significant part in any socio-technical system. Events such as the disasters that occurred at Chernobyl, Bhopal and Three Mile Island reveal the potential catastrophic nature of failure at the man-machine interface. Further to this, the NASA *Challenger* space craft accident showed us even space is not immune from human-designed technological mistakes. Although safety is constantly improving in some technologies, the concept of Human System Integration (HSI) with respect to a socio-technical system is largely ignored, or only adequately engineered following review of a demonstrated mishap [41]. By focusing early on the human element in the design, testing and implementation process, it is possible to achieve dramatic increases in system performance and overall productivity [41]. In order to achieve this, Human Factors (HF) issues require critical attention during the development of any functional system – particularly an unmanned system. When employing a UV, and seeking to combine the remoteness of the environment with some form of human intelligence, the ultimate goal is that via the use of sensors, the operator will be able to act and perform as if he or she was really present at the remote location [15]. To achieve this end, consideration of HF will remain essential to the design, development and implementation of an unmanned vehicle, thus contributing to overall system growth and maturity.

As a field of research, the exploration of human factors for UUVs, both military and commercial, is in its early stages. To date, relatively few UUV HF studies have been published in the open literature, a reflection of the infancy of this domain of research. UUVs constitute an area of growing interest due to their ability to operate at depths and in areas that are inaccessible to humans or other types of vessels. These vehicles are used extensively for underwater search and salvage, inspection, surveying, scientific exploration, and mine countermeasures. Owing to their operational capabilities, the Royal Australian Navy (RAN) employs UUVs to complete a wide range of tasks, including mine counter-measure applications and hydrographic surveillance operations. Due to the important roles these vehicles assume in such situations, it is necessary to ensure superior systems and technologies are in place in order to facilitate optimal performance - by both human and machine.

Of the open literature, the majority of HF studies relating to UUVs primarily focus on pilot training issues and techniques [42-44]. These studies explore training methodologies with the intent to examine and quantify the transfer effect of learned skills to live operations. Due to the expense and logistics involved with operating an actual UUV, training and practice is often difficult to obtain other than whilst "on the job". In an attempt to address this, Fletcher and Harris (1996) have developed and demonstrated a virtual environment based system (TRANSoM) for training ROV piloting skills. Simulation based technology can be an effective tool in pilot training and results to date have yielded comparable piloting performance between the TRANSoM system and an actual ROV [42, 43].

While simulation-based technology demonstrates effectiveness in the training arena, its use has not been extended to consider other human factors issues that pertain to UUV operations. While training will undoubtedly remain a focus for HF researchers, significant attention needs to be directed towards other features of the piloting experience which also have the ability to influence Human Performance (HP) and mission operations. Research into workload with respect to differing levels of automation, human control processes, training aspects and importantly, issues surrounding Situation Awareness (SA) for UUV operators are all very important topics which need to be fully examined [40].

Situation Awareness is a very important HF issue when considering UUV operations as it has the potential to greatly influence the success of operations. SA is a prominent HF issue as it influences performance in light of the tasks pilots must perform as part of the system.

Situation Awareness as a concept can be defined as "the perception of elements in the environment within a volume of time and space, comprehension of their meaning and projection of their status into the near future" [17]. Being 'aware' of what is happening around you and understanding what information means to you now, and in the future, is critical to the success of a task in complex settings. As the concept of SA usually applies to operational situations (where SA is required for a specific reason) it can usually be defined in terms of what information is important for a particular job or goal.

SA has been shown to be a critical element in the success of a mission [19]. If persons within the system of interest do not possess adequate SA, the performance of the system as a whole will be degraded. For this reason, SA remains an ongoing consideration during system operation, particularly for the pilots of UUVs.

Endsley (1995a, 1995b) developed a theoretical model of SA in order to provide an understanding of the processes and factors that influence the development of SA in complex settings. The model (illustrated in Figure 19) shows the overall role of SA in decision-making and performance. While SA is a stage physically separate from decision-making and performance of actions, it is highly influential in decision-making and as such, can be considered the main precursor to this process. Based on that premise, operators derive information from their environment in order to decide what to do about a situation, or to carry out any necessary actions or tasks. Intuitively, decisions about specific situations are made based on an operator's level of SA. If an operator does not possess adequate SA for a situation, it is reasonable to assume that faulty or ill-informed decisions could result as a by-product of this reduced SA.

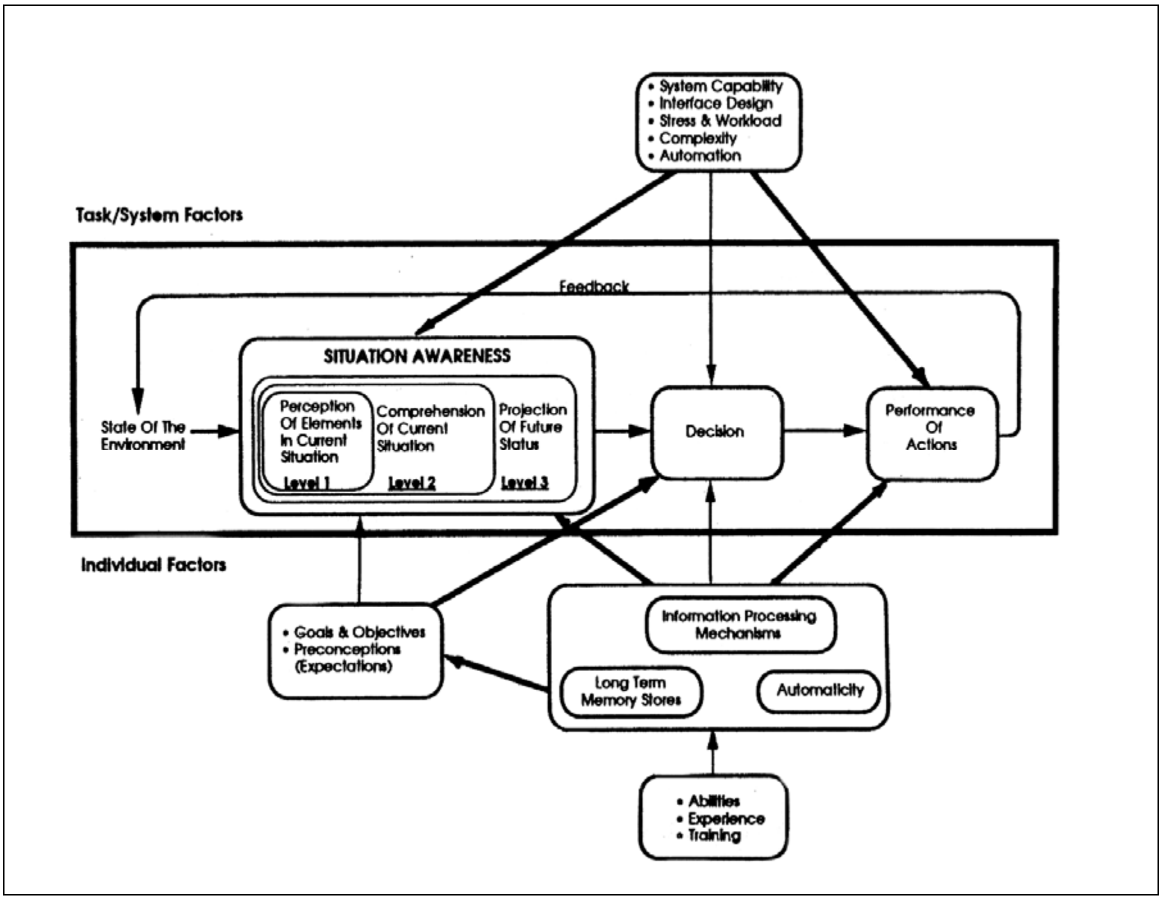

Figure 19: Endsley's model of situation awareness in dynamic decision making [17]

As a concept, situation awareness is an inherent element of what is defined under the broader heading of human performance. Human Performance refers to the level or accuracy and efficiency with which an operator completes a given task [45]. If an operator has a high level of SA, then it is feasible to suggest that overall HP within the system may also be high. In many socio-technical systems, different aspects of human performance can be measured directly from system data output. An operator's level of SA can be determined through a measure of SA and correlated against actual system data to get a feel for how SA affects different aspects of performance such as time on task and accuracy.

Many elements can combine negatively to influence an individual's level of SA and performance, however, these influences can largely be alleviated if they are duly considered during the system design phase. The effectiveness of system design appears to have a major influence on the development of a high level of SA during operational situations [27]. In order to establish the degree to which new technologies and design concepts improve or degrade operator SA, evaluation of these concepts must take place using measures of SA to determine potential positive and negative consequences of design characteristics.

As SA plays an important role in the success of operations, it is therefore necessary to examine things that influence it with the aim of improving and maintaining appropriate levels of SA. For many systems, operator SA, workload and other performance measures can be directly measured during design concept testing. Specifically, if SA is measured directly, it should be possible to select design concepts that promote SA and thus, increase the probability that operators will make effective decisions and avoid poor ones [27]. Many of the problems associated with SA such as non-integrated data, automation issues, and excess attention demands, are frequently brought on by poorly thought out system design. These factors can be detected early in the design process where corrective changes can be made to improve the design [19].

Current research into situation awareness has focused on its measurement in dynamic systems where efforts have focused on the aviation domain [18]. This has been borne out of the significant role that aircraft (manned and unmanned) continue to play within the civil and military arena. However, this is not to imply that these techniques should be confined solely to SA research in the air domain, rather the techniques available are also applicable to other domains and as such, can be applied to HF research into UUVs.

SA measurement, and the evaluation of potential design concepts, routinely takes place within the context of rapid prototyping or human-in-the-loop task simulation [19]. Although the gathering of SA knowledge can be achieved in the real time environment, measurement within a simulated environment provides researchers with greater flexibility to evaluate design concepts allowing the design process the iterations it needs in order to develop a system which promotes and helps maintain operator SA.

With the advent of simulation based technology, many of the problems associated with situation awareness and human performance can be alleviated through the system design and evaluation phase. The ultimate goal of any socio-technical system is to provide the correct environment and tools for the human operator to complete their intended task with a high degree of efficiency and a minimum of error. Poorly designed systems exacerbate error and decrease overall efficiency, however, these costly effects need not occur. Consideration and integration of situation awareness and human performance requirements should be mandatory during the development process of any system.

5.1 Information Requirements: Display Design Issues

A UUV has no onboard pilot and as a result, the success of a mission relies on proficient human operators on the ground or surface platform to ensure appropriate guidance for the task at hand. However, having correct and relevant information to aid completion of the task, remains highly influential in ensuring the success of a mission. If a pilot is not provided with adequate information, and in a manner which is easily accessible and decodable, then performance and efficiency will suffer[16]. It is therefore necessary to explore the tools UUV pilots rely on to aid safe and effective completion a mission. Undoubtedly, the Human Computer Interface (HCI) as presented to pilots via the means of their operator display (essentially a Head-Up Display (HUD)) [7], must be of sufficient calibre and relevance for them to perform the task to the best of their ability. It is for this reason that pilot information displays should be investigated to ensure pilots are being presented with information that is necessary, correct and relevant to the operational task.

Display design has a huge impact on the operation of many socio-technical systems and many human interface challenges have arisen in the UUV/ROV domain, each of which has the potential to contribute to a reduced SA, therefore leading to degraded mission performance [45]. Currently, UUV information display design has been based upon the same principles and implemented in the same way as for those unmanned vehicles operating in the air domain [13]. However, as UUVs operate in a completely different environment from that of an Unmanned Aerial Vehicle, it is not sufficient to merely employ the same principles as those explored for the air domain in UUV operations. Certain features of the underwater operating environment such as sea state, water current, salinity, temperature profiles, and turbidity have the ability to adversely influence an operational mission. In addition, one notable difference between the two operating environments is the speed at which the vehicles are operated. In the aviation domain, vehicles are operated in a very fast environment which allows swift and decisive vehicle movements. Consequently, display design becomes an issue, as within this real time environment displays may become difficult to read with rapid information changes. This increase in speed of execution and display of information, places demand on the operator in terms of information processing and reaction time when making decisions. Thus SA can be differentially affected if information is not displayed in an easily interpretable and coherent fashion. Rate of change of display information becomes less of an issue when considering display design in the underwater environment due to the reduced speed at which these vehicles operate. A reduction in speed execution in the operational environment means information displayed to pilots is presented at a less rapid rate which has the potential to reduce information processing times. A drawback of this is that as things happen in a less rapid environment, tasks take longer to execute which may hamper the maintenance of pilot SA due to the volume of information they must keep track of.

Display design is of high importance for both air and underwater vehicles due to the integral part it plays in allowing a pilot to execute a mission successfully. The speed of execution of the operating environment contrasts a major difference between the operation of these two class of vehicles however, as mentioned it is not the only distinguishing feature. As such, due to the variation between the two operating environments, it is possible that different elements may affect operating performance at both the human and the machine level. It is necessary therefore that HF research for UUVs be conducted in its own right in order to confirm or disconfirm any potential universality between the classes of vehicle.

In light of the infancy of the domain of research, it seems intuitive to seek to examine the current HCI at the level of display design and information presentation in order to answer some very important initial HF issues. In reviewing the related literature, it becomes apparent that display design is an important issue which warrants further investigation.

5.2 Current and Explored Display Issues

A number of studies have been conducted in the air and land domains which have sought to address critical issues with respect to pilot information displays [1-4, 7]. Resulting from this research, a number of principles have been identified on what constitutes a “good” or “bad” design; unfortunately however, very few of these principles have been validated in models that could help to identify the “best” design, or determine how principles trade-off against each other [46]. Furthermore, issues such as display separation, task demand and display clutter [1] have been investigated with the intention of determining the characteristics of a high-quality display in terms of content and layout that optimises pilot performance [46].

Further to this, researchers have explored 3D perspective, and multi-sensory displays to improve operator telepresence, operator SA and mission performance [40, 47-50]. Bemis, Leeds and Winer (1988) compared performance on a conventional plan-view (top down) display with performance on a perspective display. Subjects in their experiment were required to detect a threat and select the closest interceptor to deal with the threat. Bemis et al. found a significant reduction in errors of detection and interception with the use of a perspective display, as well as a reduced response time for selection of interceptors [51]. In a study investigating air traffic avoidance tasks, Ellis, McGreevy, and Hitchcock (1987) found subjects took less time to select avoidance manoeuvres and were more likely to achieve separation when using a perspective display than a conventional view display. Naikar, Skinner, Leung and Pearce (2001) conducted a similar experiment where operator performance on a conventional two-dimensional (2D) tactical display was compared with performance on a three-dimensional (3D) perspective display [52]. In concurrence with Bemis et al. (1988), results indicated an advantage for the perspective display over the 2D displays, although this was somewhat dependent on the conditions being tested.

While these researchers concluded that perspective displays showed potential to reduce errors and response time for operators, the evidence to date on this issue has not been consistent. Other researchers [53] have found that top-down plan view displays to be as good, if not better, than perspective displays when precise distance judgments were required. Perspective displays can be ambiguous regarding precise position and can introduce distortions in perceived locations in the attempt to depict depth [25, 54]. Bearing these findings in mind, the issue of distortions in perceived location is a critical one which is particularly important when considering whether to present information in a top down plan view or a perspective view to a UUV pilot. As operators can be provided with a wealth of information relating to their vehicle, how this information is displayed, and in what format becomes important. Any distortion in perceived location is a critical issue, particularly if the distortion is a result of a poor display design. Although these findings appear to lend general support to the use of a perspective display in the real time piloting of an aircraft, any distortion would have an impact on a pilot’s SA and therefore, should be investigated. While these findings relate to aircraft, they must also be considered when addressing the HF issues associated with operating a UUV. An inaccurate understanding of the vehicle's location within their environment becomes particularly important, especially during mine counter-measure operations.

In addition to providing an operator with accurate and easily interpretable information via their operator display, telepresence becomes a significant requirement. Telepresence refers to the perception of presence within a physically remote or simulated site - the ability to project an operator's perceptual, cognitive and psychomotor capabilities into distant, dangerous or simulated environments. Telepresence has been identified as a design ideal for synthetic environments [55].

Telepresence and Situation Awareness are two concepts which should go hand in hand. While the role of human operators in teleoperated systems depends largely on the system's level of automation, achieving appropriate telepresence will remain an important factor in the operation of a UUV. Situation Awareness can be considered a good indicator of operator presence within a virtual world, or when conducting remote operations of a vehicle such as an unmanned air or underwater vehicle.

So how do we achieve adequate telepresence? What type of display promotes telepresence and enhances an operators situation awareness and human performance? The literature suggests that 3D perspective displays have a general advantage over their 2D counterparts in providing more global awareness [8] however, this finding is not universal [30].

In reviewing the literature on display design, it becomes apparent that there are costs and benefits to presenting data in both a 2D and 3D format. Consequently, the effectiveness of technologies such as a UUV will depend on the particular display options chosen and the context within which the technology is applied.

5.3 Head-Up Displays

One widely accepted way to provide information to pilots is through the use of a Head-Up Display (HUD) which integrates information from sensors and the outside world into a working picture of the operating environment. The concept of a HUD is not novel; in fact, the world's first flight worthy ground-referenced HUD was developed in the 1960's by the Australian Aeronautical Research Laboratory (formerly ARL, now DSTO). These displays are now used in virtually every combat aircraft in the world. The advantages of a Head-Up Display over conventional head-down displays which require the pilot to break visual continuity with their outside world have been observed [56-58], and the positive impact HUDs have had on flying has been well documented [59, 60]. A number of benefits have been associated with flying with a HUD, including improved aircraft flight control, particularly in areas such as instrument approaches in inclement weather [57]. HUDs have the benefit of lessening pilot workload while presenting the information in a position that should keep them well informed of the systems operation [38]. However, the benefits associated with the implementation of a HUD do not mean that they are infallible, as it is conceivable that there may be situations when the benefits of HUD use are minimal, nonexistent, or possibly reversed [46].

While there is general consensus that HUDs are useful in presenting information to a pilot, how this information is displayed can have a marked impact on a pilot's performance. HUDs can display information to pilots in a variety of ways from graphical format, to straight numerical output, to an egocentric vs. exocentric view of flight data. In a detailed examination by Johnson & Roscoe [20] the issue of how to display information to pilots is explored as it is noted that pilot performance can be influenced by display design and information content. When considering a pilot's frame of reference with respect to how they view their vehicle; either as egocentric (vehicle referenced), or as an exocentric (world referenced) frame of reference, this has the potential to impact on a pilot's ability to achieve and maintain SA. This in turn will influence performance and as a consequence, reduce the effectiveness of a mission. In short, the manner in which information is displayed, particularly to a UUV pilot, becomes a very important issue.

While studies have been conducted to demonstrate the usefulness of HUDs in automobiles and aircraft [61] being operated by people in the 'live' environment, little has been done to test the effectiveness of Head-Up information displays for remotely piloted vehicles. Drawing on research conducted for HCI in the live world, examination of display design and information content as it applies to unmanned underwater vehicles is suggested as a priority HF research agenda. It is conceivable that display design and information content for UUV operational interfaces will differ significantly from that of a real time aircraft display and as such, operators of a UUV may require extra information, such as tactile feedback of their vehicle in the operational environment for example.

Human performance, specifically human control processes and situation awareness are two prominent HF issues that need to be addressed with respect to UUV operations. Necessarily ingrained in the process of display design, HP & SA play a very important role in the development and evaluation of new systems and interface designs.

Due to the relative infancy of the UUV HF research field, a necessary step is to evaluate the suitability of existing UUV interface designs with the intent to determine how they aid and promote superior system performance. A good display design is an undoubtedly necessary tool to help promote and maintain a high level of operator performance and situation awareness. Display design should be viewed therefore as a top priority when considering the human factors issues associated with operating an Unmanned Underwater Vehicle.

The aim of the present study is to extend on current work conducted for display design in the aviation domain and apply it to the operation of UUVs in order to help determine any universality between the underwater and air domains.

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Appendix A: - Joystick movements

The joystick operates in two modes. These modes allow for the full 6 degrees of freedom (movement) of the vehicle. The two modes to be aware of are;

- Flight mode;
- Hover mode.

The default mode is **Flight mode**. The vehicle will start each scenario in Flight mode. In this mode, the vehicle acts much like an aircraft. The joystick controls for **Flight mode** are as follows:

- **Acceleration**: Controlled by the throttle lever at the bottom centre of the joystick base. The throttle must be set to the full off position (pointing towards the minus sign) at the commencement of each scenario. Moving the throttle forwards and backwards will control acceleration and deceleration of the vehicle.

- **Pitch Control**: Pushing the joystick straight forward and pulling the joystick straight backward in Flight mode will control the pitch of the vehicle. When the joystick is pushed or pulled and allowed to return to the neutral position, the vehicle will maintain the pitch set by the operator.

- **Roll Control**: Pushing and holding the joystick left to right in Flight mode will control the roll of the vehicle. When the joystick is moved to the left or right and allowed to return to the neutral position, the vehicle will maintain the roll set by the operator.

- **Yaw Control**: Twisting the joystick from left to right will control the yaw (heading) of the vehicle. When the joystick is twisted left or right and allowed to return to the neutral position, the vehicle will maintain the yaw (heading) set by the operator.

- **Button 11**: Button 11 is located to the left of the joystick. Button 11 will switch the vehicle to Reverse Flight to enable you to fly backwards if required. Please note to activate Reverse Flight, the throttle must be returned to the full off position. The current direction of flight is displayed in the bottom left hand corner of the operator screen in each scenario.

- **Button 12:** Button 12 is also located to the left of the joystick. Button 12 will switch the vehicle back to Forward Flight from Reverse Flight if required. The current direction of flight is displayed in the bottom left hand corner of the operator screen in each scenario.

There are two ways to switch the vehicle controls between **Flight mode** and **Hover mode**.

Acknowledgement of the current mode is displayed in the bottom left hand corner of the operator screen in each scenario.

Modes can be selected and maintained by;

- **Selecting between Flight and Hover mode:** Clicking the 'hat' on top of the joystick forwards and backwards will select between flight and hover mode. Once clicked in either direction, the vehicle will remain in that mode until the operator selects another mode.

- **Temporary mode selection:** The vehicle can be temporarily switched between each of the modes by pulling and holding the trigger located at the position of the forefinger on the underside of the joystick.

There is no restriction to what mode the operator may fly the vehicle in. He or she may choose to fly in a combination of Flight and Hover mode for greater control. The joystick controls for **Hover mode** are as follows:

- **Acceleration**: Controlled by the throttle lever along the bottom centre of the joystick base. The throttle must be set to the full off position (pointing towards the minus sign) at the commencement of each scenario. Moving the throttle forwards and backwards will control acceleration and deceleration of the vehicle.

- **Depth Control**: Pushing the joystick straight forward and pulling the joystick straight backward in Hover mode will control the depth of the vehicle. When the joystick is pushed or pulled and allowed to return to the neutral position, the vehicle will maintain the depth set by the operator.

- **Horizontal Displacement**: Pushing and holding the joystick left to right in Hover mode will control the sideways movement (horizontal displacement) of the vehicle. When the joystick is moved to the left or right and allowed to return to the neutral position, the vehicle will maintain the position set by the operator.

- **Yaw Control**: Twisting the joystick from left to right will control the yaw (heading) of the vehicle. When the joystick is twisted left or right and allowed to return to the neutral position, the vehicle will maintain the yaw (heading) set by the operator.

You are encouraged to familiarise yourself with the joystick controls and engage the vehicle in all degrees of freedom during your familiarisation session, and also during the experimental scenarios.

If you have any questions about the control of the vehicle using the joystick, please ask the researcher during your 5 minute control familiarisation session. These joystick control instructions will not be provided for reference during the actual scenarios.

Appendix B: HMAS Waterhen Visit: Plan for information collection

As part of MPD's Human Factors investigations for Unmanned Underwater Vehicles, a focus group session has been arranged in order to interview operators of the Double Eagle mine hunting UUV. The focus group will take place on Thursday August 5th at HMAS Waterhen.

The session will be conducted to help gather information on UUV operator activities. This information will be compiled and used as accompanying analyses for a DSTO based experimental program which will investigate the effect of display design on UUV operator Situation Awareness (SA) and human performance.

B.1. Outline of information being sought

As mentioned, the focus group session will take place in order to gather information on operator activities and information requirements for the task of flying an MDV. With the consent of the participants, the session will be tape recorded and written records will be taken in order to gather generic and detailed data.

Operators will be asked to talk about the current system in order to gain a general idea of what each operator does in the course a mission and any problems they encounter.

The session will have a broad focus and will cover a range of topics designed to collect as much information as possible. Broadly, information sought will be related to the following:

- The nature of a Typical Mission
- A typical operational environment
- Essential information to complete piloting task
- Possible improvements to the current system (e.g. control mechanisms, HCI upgrade etc)

Part of the session will consist of stepping through a typical mission with a view to identifying the moment-by-moment task demands on the MDV operator. The information required by the operator to meet the task demands will also be identified, together with the available information sources.

At the end of the session, a prototype situation awareness display screen will be presented for comment. The display has been designed to be applicable across the widest possible range of underwater remotely operated vehicle types and missions, and frank discussion of its merits with respect to MDV operations will be welcomed.

B.2. Goal Directed Task Analyses

In order to test pilot skills and knowledge requirements for the task at hand, the session will also include discussion of the major goals and subgoals that are to be achieved during a typical mission. A Goal Directed Task Analyses (GDTA) will be conducted subsequent to the session and will be based on the information provided. The GDTA will obviously examine the goals of the mission (e.g to detect/identify/classify an object) and the steps that lead up to, and tasks that need to be completed, in order to achieve overall operational goals.

The information contained in the GDTA will be used directly to determine the Situation Awareness (SA) requirements of the operators. Subsequent SA probe questions will be developed to be asked during the experimental flying sessions. The SA questions will be developed around the sort of information typically displayed to the pilots (in the experimental simulation, via the Head Up Display HUD). Pilots will be able to answer the questions based on how well they use they use the information contained in the HUDs during the piloting experiment.

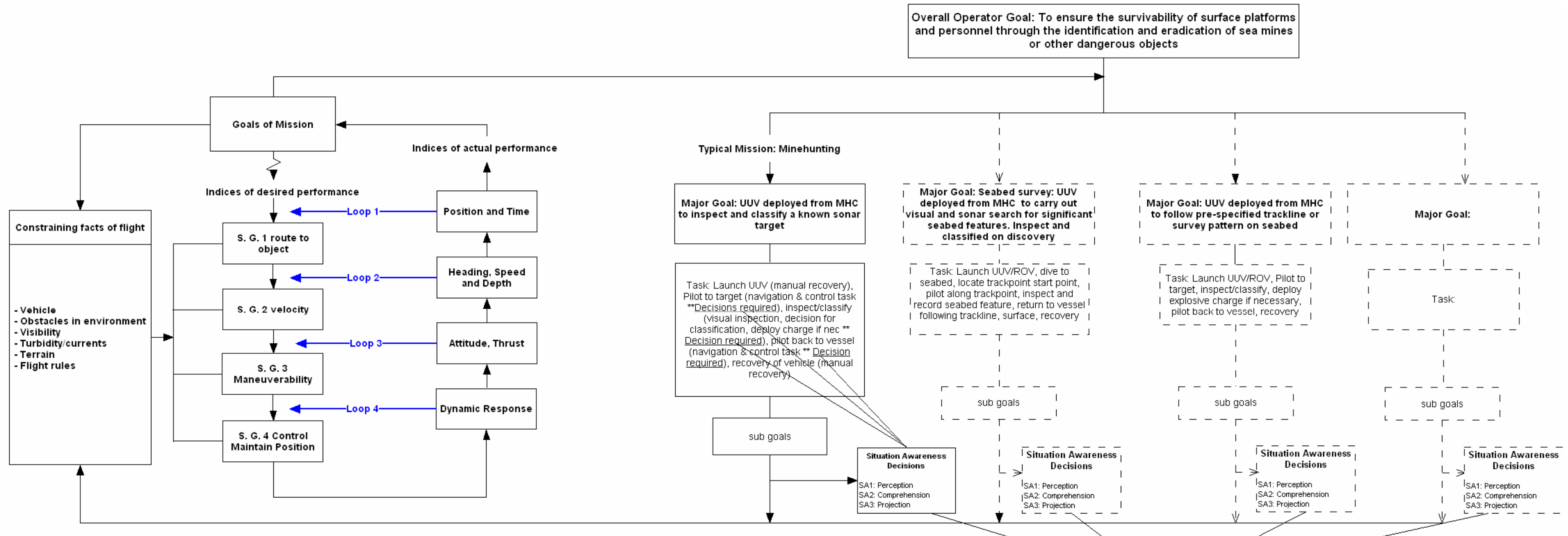
B.3. Any Stand Out Issues?

The interview group will be asked to give their thoughts on any issues they feel impede their ability to complete their tasks and achieve their goals. Broad topics likely to be covered include:

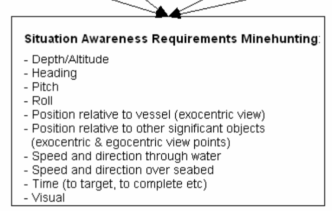
- Discussion on physical controls for the vehicle, e.g. do the pilots consider the current two joystick setup to be sufficient? Have they thought about the possibility of one joystick controller for ease of use? Do they utilise the step functions for fine controlling more than using the joysticks?
- Issues associated with cable management?
- Training issues? What does the current training consist of? Is the current pilot training adequate? If not, what would they change?

If anyone has any questions or concerns in relation to the session, please contact either Sarah-Louise Donovan (DSTO) on (03) 9626 8618 (Sarah-Louise.Donovan@dsto.defence.gov.au) or Peter Henley (Curtain University) on (08) 9266 3555 (pjhenley@iinet.net.au).

Appendix C: Goal Directed Task Analysis (GDTA)



Situation Awareness Queries		
Situation Awareness queries generated from GDTA. (Focus group transcript not included due to contents).		
SA queries have been derived from the Focus group session and reflect SA requirements for UUV piloting tasks		
		SA Level
Q1	Estimate your current pitch angle (in degrees)	L1/2
Q2	Estimate your current roll angle (in degrees)	L1/2
Q3	Estimate your current speed (in knots)	L1/2
Q4	Estimate your current depth (in metres)	L1/2
Q5	Estimate your current heading (in degrees relative to north)	L1/2
Q6	Estimate the distance (in metres) to the next waypoint you will reach?	L2
Q7	Estimate the number of the next waypoint you will reach?	L3
Q8	Are you currently accelerating, decelerating or neither?	L3
Q9	Which direction will you turn in the next 10 seconds? (left, right no change?)	L3
Q10	Estimate heading required to reach the nearest waypoint	L2
Q11	What mode are you currently in? (Flight or Hover?)	L1/2



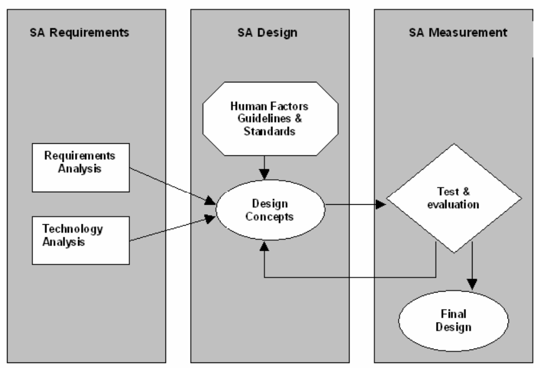


Figure 1. User Interface design process as cited in Endsley, 2003 (M. R. Endsley, Bolte, B. & Jones, D. G., 2003).

A model of the procedure that was undertaken. First establishment of the SA requirements, 2nd involved the design of suitable displays based on I/O & O/I principals. Thirdly, measurement in the form of test and evaluation (Simulation environment utilising SAGAT and performance measures) to determine final design. This is an iterative process which is highly valuable when determining display design requirements that will enhance performance and SA.

This Goal Directed Task Analysis (GDTA) was conducted based on the outcomes from a number of Focus Group sessions with experienced UUV pilots at the Navy's Mine Warfare Faculty. Due to the nature of the information provided in the Focus Group sessions, the official transcripts can not be provided with the GDTA. However, the transcripts directly contributed to the determination of Situation Awareness requirements for UUV operations (Minehunting). The Situation Awareness requirements as outlined above formed the basis of information to be displayed on each of the screens provided in the experimental conditions. The same information was presented in each of the three conditions, only the format of presentation differed. The Situation Awareness queries that were developed were a result of the GDTA and were designed to assess participants level of Situation Awareness with respect to the displays presented. For a more detailed description of the development of this model to represent the GDTA, please contact the author.

Appendix D: Explanatory Statement

D.1. Project Title: Investigating the Effects of Display Design on Unmanned Underwater Vehicle Pilot Performance.

My name is Sarah-Louise Donovan and I am doing research under the supervision of Prof. Tom Triggs a Professor in the Department of Psychology towards a PostGrad Dip in Psychology at Monash University.

The aim of this research is to investigate the effect of different user interface designs on the performance of an Unmanned Underwater Vehicle (UUV) operator/pilot. The experiment will involve presenting participants with three competing displays implemented within a simulated environment. Using the simulation environment, participants will be asked to navigate a path using information provided to them; verbally by the researcher, and visually by their Head-Up operator display. Measurements of human performance (speed, time, accuracy) and Situation Awareness will be gathered in order to help establish if a particular display type or configuration provides superior performance among UUV operators/pilots. The experiment will go for approximately 1 – 1.5 hours duration.

Data from the experiment will be collected in two forms being; human performance measurements (for speed, time taken and accuracy) will be collected by the simulation program during the experimental conditions and secondly; measurements will be taken on operator Situation Awareness throughout the experiment. Situation Awareness data will be collected electronically by a series of probe questions asked about each experimental condition. The simulation will be paused at random intervals and Situation Awareness questions will be presented requiring a response for the mission to continue.

The outcome of this experiment has implications for both commercial and military use of UUVs and as such, the results of this study will be made available to relevant Defence personnel and also, will possibly be published in relevant publications.

Each participant will be asked to sign a consent form indicating their voluntary participation in the experiment. Names will not be recorded for the experiment and data collection instead participants will only be required to provide the researcher with their date of birth and gender. Access to data collected will be restricted to myself as researcher and the project supervisor. When the project is completed and written up, each participant will receive a copy of the results to acknowledge their contribution to the process. All written reports and data will be stored for at least 5 years as prescribed by the university and DSTO regulations.

The risk of physical and psychological stress associated with this project is judged to be minimal. The nature of the experiment and data collection is designed to be minimally intrusive and should pose little inconvenience or discomfort to participants. Participants are merely asked to participate in a simulated 'computer game like' flying exercise where their knowledge of the situation and their performance will be recorded and compared within the bounds of the experiment.

You may withdraw from the experiment at any time simply by informing myself or another researcher involved in the project. You will not be required to give a reason either to myself or any other researchers, and neither not participating at all nor withdrawing will have a negative effect on your employment position or promotion prospects.

If you have any queries regarding this project or would like to be informed of the aggregate research findings, please contact telephone the researcher on (03) 9626 8618 or fax (03) 9626 8652.

You can complain about the study if you don't like something about it. To complain about the study, you need to phone 9905 2052. You can then ask to speak to the secretary of the Human Ethics Committee and tell him or her that the number of the project is 2003/809. You could also write to the secretary. That person's address is:

The Secretary
The Standing Committee on Ethics in Research Involving Humans
PO Box No 3A
Monash University
Victoria 3800
Telephone +61 3 9905 2052 Fax +61 3 9905 1420
Email: SCERH@adm.monash.edu.au

Thank you.

____

Sarah-Louise Donovan
(03) 9626 8618

Appendix E: Consent Form

Project Title: Investigating the effects of display design on Unmanned Underwater Vehicle pilot performance

I …………………………………agree to take part in the above Monash University/DSTO research project. I have had the project explained to me, and I have read the Explanatory Statement which includes information on how to contact the researchers, which I keep for my records. I understand that agreeing to take part means that I am willing to:

- Take part in a simulated flight experiment
- Allow data from my participation to be recorded and analysed for each experimental condition
- Be interviewed by the researcher in order to determine my level of Situation Awareness for the experimental conditions I am participating in
- Make myself available for a further interviewing and experimental condition testing should that be required

As outlined in the Explanatory Statement, I understand the purposes for which the information is being collected. I understand and acknowledge that the risk of physical and psychological stress associated with this project is judged to be minimal. The nature of the experiment and data collection is designed to be minimally intrusive and should pose little inconvenience or discomfort to participants. Should a serious event of emergency occur during the conduct of the research, I understand that emergency first aid facilities will be on hand to deal with any physical problems. Should any problems of a psychological nature arise, I acknowledge that the matter will be immediately forwarded to a relevant and qualified health care individual for treatment.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.

I understand that I will be given a transcript of data concerning me for my approval before it is included in the write up of the research. I understand that data collected will be retained for a period of 5 years.

I also understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

Signature ………………………………… Date…………………

Appendix F: Task Description

F.1. Task

The aim of this research is to investigate the effect of different user interface designs on the performance of an Unmanned Underwater Vehicle (UUV) operator/pilot. This experiment will involve presenting participants with three competing displays implemented within a simulated environment.

Using the simulation environment, participants will be asked to fly a mission using information provided to them both verbally by the researcher, and visually by their Head-Up operator display. Human performance and Situation Awareness data will be collected. Human performance data will be collected directly from the simulation program and logged. Situation Awareness data will be collected electronically by a series of probe questions asked about each experimental condition.

Participants will be given a five minute practice session to familiarise themselves with joystick controls prior to commencement of the experimental conditions. You will be provided with a description of the joystick controls for use during the practice session. It is advised that you familiarise yourself with the joystick and all of the vehicles movements in order see how the vehicle will respond to your input. You will be asked to use the vehicle in all degrees of freedom during the experimental conditions. At the conclusion of the 5 minute familiarisation session, the researcher will initiate the first of the three scenarios. Participants will be given 15 minutes to fly each scenario. You may fly at what ever speed you feel comfortable.

The experimental task will require you to fly towards a set of waypoints located on a chart in the top right hand corner of the operator screen. You must use the instruments and information provided to you on the operator screen to effectively manoeuvre the vehicle towards the waypoints. The researcher will provide you verbally with a relative heading for each waypoint, however this will be done only once for each waypoint. You will need to follow the researchers heading initially in order to progress towards each of the waypoints. Participants must fly towards each waypoint and pass as close as possible to it, if possible flying through it. Participants must acknowledge to the researcher when they establish visual contact. When the participant acknowledges visual contact of the waypoint, the researcher will provide the participant with a relative heading to the next waypoint. Participants should commence along that heading, making adjustments where necessary to reach the next waypoint. The vehicle is restricted to travel below the water surface so reaching waypoints may require the operator to navigate around and/or over objects in order to reach each waypoint.

Waypoints will become visible when the circular vehicle indicator overlays the red cross in the chart at the top right hand corner of the operator screen. The circular vehicle indicator will overlay the cross if you are in the right area. You should be able to see the waypoint when you are approaching it if the vehicle circle is overlaying the red cross somewhat. Waypoints will not necessarily be positioned on the ground. They may be located in the water column above you. If you do not immediately see the waypoint as your vehicle mark approaches the waypoint cross on the reference chart, participants should survey the surrounding area both above and below them to locate the waypoint.

The aim of the task is to use the instruments provided to help you reach the waypoints. Participants will be required to utilise the instruments provided to help them gain Situation Awareness and to enable them to sufficiently maneuver the vehicle towards each of the waypoints. In order to assess a participants level of Situation Awareness, at random intervals during each scenario, the simulation will be paused and participants will be asked a series of Situation Awareness questions relating to their Head-Up instruments and where they are within their environment. The operator display will be temporarily blanked out and questions will be presented to assess the participants level of Situation Awareness (Situation Awareness defined as "*the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of the status of these elements into the near future*" [17, 18]. When prompted with a Situation Awareness question, please verbalise your answer to the researcher so they can enter your answer in the box on the screen. Once your answer is logged, the scenario will continue.
The aim of the experiment is to utilise your instruments to make sure you are where you are meant to be to reach the next waypoint. Try to reach as many waypoints as you can during the 15 minute time limit. Be aware that you will not reach all waypoints in the time permitted.

The vehicle will be initially neutrally positioned in terms of roll. Try to keep the vehicle as flat as you can. Be aware that the vehicle is highly maneuverable and that it is very easy to flip (both pitch and roll) the vehicle. Participants should also keep the vehicle as close as possible to between 10-20 metres to the seabed at all times.

Good luck!

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Sarah-Louise Donovan and Tom Triggs

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Display Design, Inside-Out, Outside-In, Situation Awareness, Human performance

19. ABSTRACT

The aim of this research was to investigate the effect of different user interface designs on the performance of an Unmanned Underwater Vehicle (UUV) pilot. Participants in this study were 23 males and 3 females who took part in a remote piloting experiment. Participants were each presented with three display designs; a display analogous to the current Mine Disposal Vehicle (MDV) Baseline display, an Inside-Out (fixed vehicle) design and an Outside-In (moving vehicle) design and were asked to fly a simulated mission. During each condition, Situation Awareness (SA) and Human Performance (HP) measurements were taken. Results indicated a significant relationship between display design and level of situation awareness and human performance on a number of measures. Significant differences in situation awareness were observed between display designs for vehicle roll and depth. Results also indicated significant differences between the display designs for the number of control reversal errors observed for roll, the number of waypoints reached, the final odometer reading and the speed of approach to the first waypoint. A significant preference was revealed for the Outside-In display design. Results from this study indicate that UUV pilot situation awareness and performance can be enhanced by modifying and improving display design. Results of this study have implications for the use of unmanned vehicles in the wider air and land domains, as well as the underwater domain.